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DESERT RESEARCH INSTITUTE
UNIVERSITY OF NEVADA SYSTEM

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ABSTRACT

A radiological characterization has been conducted at the former Kellex Corporation site in Jersey City, New Jersey. Although several prior surveys and a remedial action were conducted, there was still a need for more information about the radiological condition of the site. A grid was established on the site and the surface was surveyed by a mobile in situ detection system. Trenches were systematically dug in an attempt to find subsurface areas of contamination. Material from the trenches was surveyed by the in situ measurement system and trench sidewalls were soil sampled and surveyed using portable dose rate and count rate instrumentation. Results of the survey indicated that radioactivity levels on the site were at or near background. Small amounts of contaminated material were found but not enough to exceed the guideline specified.

ACKNOWLEDGMENT

The author is indebted to Allen E. Fritzsche for his reporting on EG&G activities and to Richard L. Powell for the report on Eberline's participation in the project.

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RADIOLOGICAL CHARACTERIZATION OF THE KELLEX SITE

INTRODUCTION

Historical Background

The Kellex site is located approximately two miles southwest of downtown Jersey City at the intersection of New Jersey Route 440 and Kellog Street. The site, originally consisting of 43 acres, is on landfill near the Newark Bay.

From the early 1900's until the early 1940's the Kellex site was the location of the M.W. Kellog Company. The plant during this time was primarily devoted to various phases of metal fabrication but, during World War II, the company began to specialize in pure and applied engineering. Under federal contract the company became heavily involved in the design and construction of a pilot gaseous diffusion plant for uranium enrichment as a part of the Manhattan Project. The purpose of the plant was not production of uranium enriched in ^{235}U but to design and demonstrate units for the process. In 1947 the Kellex Corporation became involved at this location in constructing a pilot plant for mixer-settlers in solvent extraction of uranium. This activity continued until the Kellex facility was closed in 1952.

All buildings dating from this period have been removed from the site. About two-thirds of the site has been released and developed into a shopping center. The remaining land is covered by weeds, concrete, rubble, asphalt, and miscellaneous debris. Foundations and concrete pads of several of the World War II buildings still remain.

Over the years since the closing of the plant, there have been several radiological surveys of the site. In June of 1953, after extensive decontamination procedures, Vitro Corporation of America published a "Contamination Status Report" concerning the

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Jersey City laboratory (7). They reported that contamination criteria at that time were not exceeded except for some isolated spots. No removable alpha or beta-gamma contamination was observed in the accessible areas of the laboratory.

A survey was done in September 1977 by the Health and Safety Division of Oak Ridge National Laboratory (ORNL). At that time only three buildings of World War II vintage remained. These buildings and a significant fraction of the property were surveyed to give a representative sampling of the radiological condition of the site. They state "the results of the radiological survey indicate the radiation and radioactivity (contamination) levels on the Kellex property are indistinguishable from background with the exception of a few isolated and well-defined spots on or near the site of the former Kellex Laboratory building. With the exception of these spots of low-level contamination, the Kellex property appears to meet pertinent guidelines for the release of property for unrestricted use" (4).

Prior to the ORNL survey of March 1979, the remaining original buildings surveyed previously in 1977 had been demolished. This survey located several additional areas having significantly higher than background gamma exposure rates, and it was decided to undertake remedial action. Envirosphere, a division of Ebasco Services, Inc., began excavation at the Kellex site in July 1979 and completed excavation and backfilled with debris by January 1980. About 1,000 barrels of contaminated soil were removed from the isolated areas delineated by ORNL. Envirosphere's report states that on the basis of their analysis, "further remedial action for natural uranium in soil at the Kellex site is not warranted by existing and proposed guidance" (5).

In order to make informed decisions about possible additional remedial action or the suitability for certification, more information was needed regarding the radiological condition of the site. This involved a surface and subsurface characteri-

zation of the remainder of the Kellex site to discern areas containing radiological contamination above background levels. (In this report these areas will be referred to as anomalies or anomalous areas.) To accomplish this, several objectives were established and are presented below.

1. Measure (survey) all the gamma ray photopeaks that are practical to measure. Concentrated effort would be directed toward those gammas from the ^{238}U series and the ^{232}Th series of radioisotopes.

2. Survey as much of the surface area and subsurface soil of the site as practical.

3. Evaluate the data during the survey for anomalous or elevated concentrations to ascertain whether or not more data should be collected.

4. Store the data on magnetic tape for further assessment and long term storage.

5. Evaluate the data to estimate the natural radiologic character of the site, and delineate those areas that display elevated levels of radioactivity.

6. Report and disseminate the data and results of data evaluation.

Survey Guidelines

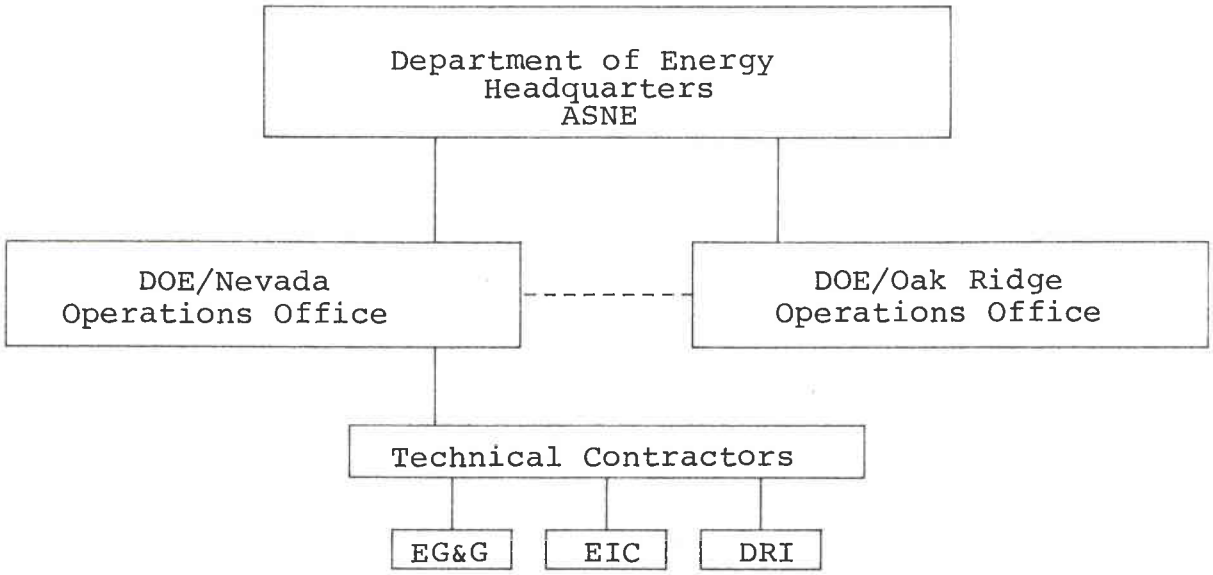
The radionuclide of primary concern at Kellex is excess ^{238}U in the soil. The cleanup criterion specified in the June 1980 criteria document (Appendix A) is 40 pCi/g of ^{238}U in the top 20 cm of soil, averaged over a 400 m^2 area. The

implementation section of the document also specifies that subsurface sampling will be performed to locate quantities of contaminated soil sufficient to exceed the surface criterion. The document further stated that "care will be taken to explore enough of the subsurface in areas of suspected contamination that a high degree of assurance is provided that significant quantities of contaminated soil have been located and removed."

Since this survey was a characterization and not a cleanup, the criterion was used only as a guideline. This guideline might be interpreted as: "Find any 400 m^2 area 20 cm thick containing an average of 40 pCi/g of ^{238}U or more."

CONTRACTOR FUNCTIONS

Before discussing the specific functions of the different contractors, a general overview of project management is helpful. The following chart represents the management relations of the contractors and the Department of Energy.



EG&G INC

The mobile radiation detection system used for the surface and subsurface surveys was maintained and operated by EG&G. This system was used for the entire surface characterization and the surveying of spoil piles (spoil pile being that soil and debris removed during the trenching process). The EG&G team provided quality assurance of the in situ system by performing three system calibrations each day and by constant monitoring during data acquisition. All data printouts were examined to insure that proper interpretation of data was made and that any anomalous areas were immediately made known to other contractors. In addition, routine maintenance was performed weekly to insure optimal performance of the mechanical systems.

A description of the in situ measurement system capabilities are presented in the following sections.

The In Situ Gamma Survey System -- ^{238}U, ^{235}U and ^{232}Th or their respective daughters emit gamma rays which can be used to quantify these radionuclides. A mobile gamma measuring system, designed and operated by EG&G for the Nevada Operations Office of the Department of Energy (DOE/NV), was utilized to perform these measurements. This system had previously been used to locate and quantify gamma emitting radionuclides in the soil of Enewetak Atoll and Johnston Island in the Pacific.

System Components -- The in situ gamma survey system (Figure 1) consists of the following major components:

1. The tracked vehicle.
2. An intrinsic germanium detector and collimator shield.
3. A pneumatic mast capable of locating the detector from zero to 7.4 m above the ground.
4. A 4096 channel pulse height analyzer.
5. A Hewlett Packard 9831A calculator with tape cartridge and printer.

The Germanium Detector and Shield -- The planar type intrinsic germanium (IG) detector is perhaps the most vital part of the system (Figure 2). The chief merit of this type of detector is its high energy resolution of detected photopeaks, typically 1-2 keV full width half maximum (FWHM). This enhances the ability to identify individual photopeaks and quantify the isotopes detected relative to other types of gamma ray detectors. The system was calibrated to measure gamma rays of energy up to 1500 keV. However, gamma penetration of the shield is significant above 600 keV and the accuracy of calibration is known to decrease. It is not known how much the calibration is off for the higher energies.

A conical shield (Figure 2) is mounted on the detector to restrict the detector view to a given solid angle and thus a fixed circular area on the ground. The physical angle of the cone is 50° from the vertical; however, the cut off angle at which gammas cease to enter the crystal is approximately 60° for gammas with energies between 0 and 600 keV.

The circle-of-view diameters for those detector heights used at Kellex are:

IG detector Height (m)	Approximate Field of View Diameter (m)
.5	2.0
1.0	3.5
1.5	5.0
3.0	10.0
4.0	14.0
7.4	26.0

The intrinsic germanium detector was calibrated for photopeak sensitivity to gamma emitters in soil by two methods, (1) by direct measurement of known concentrations of potassium, uranium and thorium at simulator pads in Grand Junction, Co., and (2) by laboratory point source angular response measurements folded into a sensitivity computation. These two methods agree within ± 15% over the energy range of 0 to 600 keV.

This information and soil density measurements taken at Kellex determined the conversion factors used to convert photopeak count rate to radionuclide concentrations. The conversion factors used for this survey are given in Table 1.

Minimum Detectable Activity (MDA) -- The minimum detectable soil activity for the in situ gamma system is dependent on the signal count rate and the background count rate. The in situ system uses a photopeak (signal) energy window and two background windows on either side of the signal window chosen so that the total width of the background windows is equal to the width of the signal window. Then:

$$S = T - B \qquad (1)$$

where S = signal count

T = total count in signal window

B = background count.

Figure 1. The In Situ Measurement System.

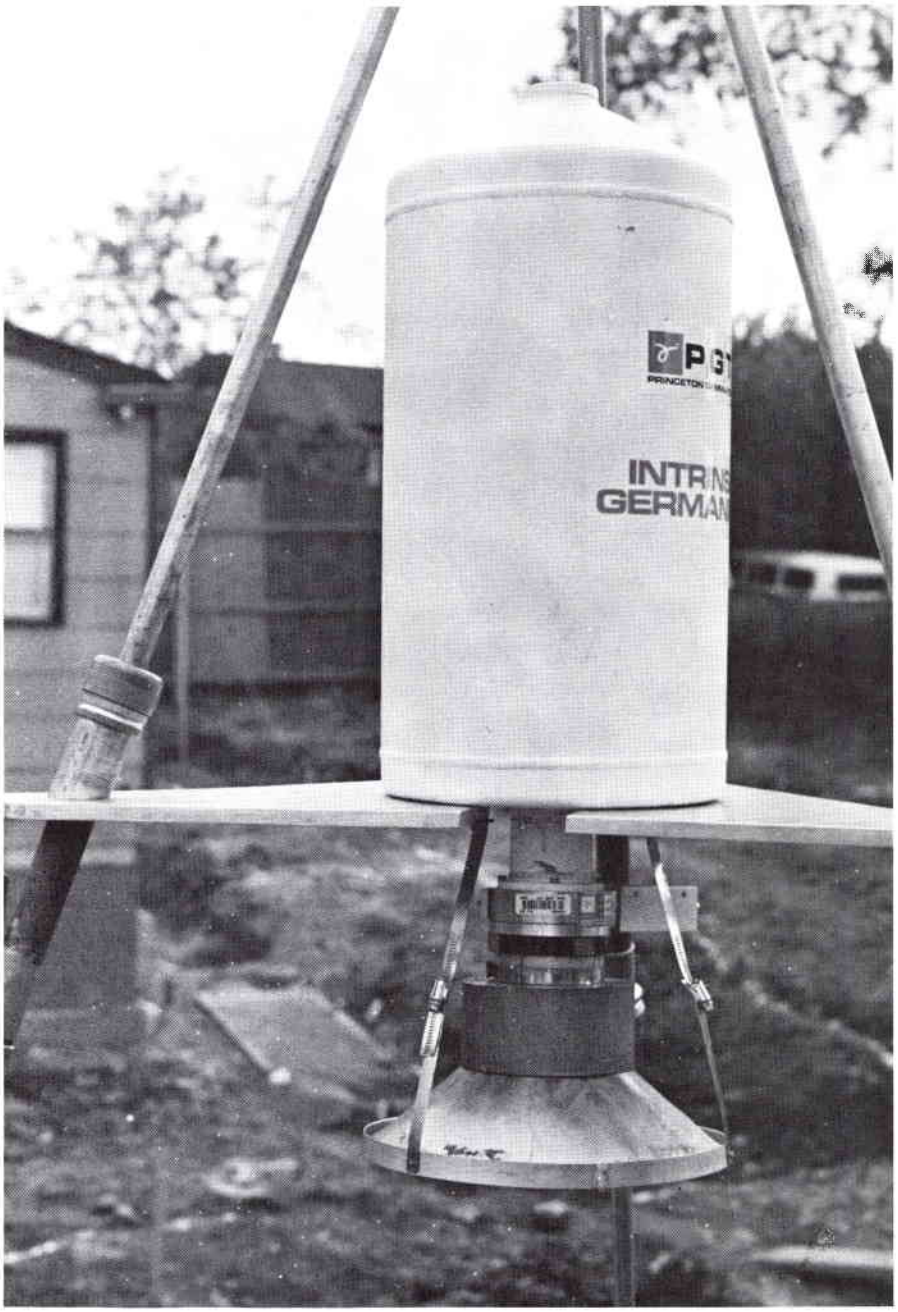


Figure 2. The Intrinsic Germanium Detector.

TABLE 1

Photopeak Count Rate to Radionuclide Concentration Coversion Factors (in pCi/g per count/sec) Used at Kellex

Isotope	Gamma Energy (keV)	Detector Elevation (m) .5	1.0	1.5	3.0	4.0	7.4
Am^{241}	59.5	6.9	7.0	7.2	7.3	7.8	8.7
Th^{234}	63.3	75.7	77.2	78.5	80.0	85.7	95.7
Th^{234}	92.8	53.6	54.5	54.8	55.7	58.5	63.1
Ra^{226}	186.1*	33.7	34.2	34.4	35.0	36.7	39.7
U^{235}	185.7*	3.5	3.6	3.6	3.7	3.9	4.2
Pb^{212}	238.6	7.3	7.4	7.4	7.5	7.9	8.5
Pb^{214}	295.2	25.4	25.5	25.5	26.1	27.2	29.0
Pb^{214}	351.9	15.0	15.0	15.0	15.3	16.0	17.1
Tl^{208}	583.1	24.3	24.6	24.9	25.2	26.4	28.4
Bi^{214}	609.3	18.6	18.8	19.0	19.3	20.1	21.7
Cs^{137}	661.6	11.0	11.1	11.2	11.4	11.9	12.9
Ac^{228}	911.1	34.5	35.0	35.3	35.9	37.5	40.3
Bi^{214}	1120.4	86.5	87.3	88.3	89.2	92.2	99.4
K^{40}	1460.8	114	115	116	117	122	129

* The peak near 186 keV consists of gammas from both ^{226}Ra and ^{235}U. The conversion factor for ^{226}Ra is correct only when the ^{238}U chain is in secular equilibrium down to ^{226}Ra and when the ^{235}U is 0.7%, by weight, of ^{238}U (the normal relationship between ^{235}U and ^{238}U). The ^{235}U conversion coefficient is that computed for ^{235}U gammas only at 185.7 keV.

This can be rewritten as:

$$S = (S + B) - B$$

with a standard deviation of

$$[S + 2B]^{1/2} \qquad (2)$$

when the normal statistics apply, i.e., independently distributed Poisson processes.

We define the system MDA for any single photopeak as that level of signal (defined by Equation 1) which is three times the standard deviation due to background of the measurement.

$$MDA = (3[2B]^{1/2})*C/t, \qquad (3)$$

where C is the conversion factor to pCi/g,

and t is the measurement time in seconds.

MDA is also site specific. Composition of soil and natural background activity at a site are influencing factors in determining MDA.

The software in the computer of the in situ system evaluates specific photopeaks in real time from the energy spectrum obtained from each measurement. The results are printed out immediately for the operator's interpretation. These results include the isotope name, gamma energy photopeak count and estimated soil concentration. A list of the routinely measured isotope gamma photopeaks, associated gamma energy, minimum detectable activity at Kellex and the use of the measurement are given in Table 2.

System Depth of View -- Gammas originating in the soil are attenuated by the soil so that the number of uncollided gammas reaching the detector decreases exponentially with depth of origination in the soil. The mean free path (MFP in g/cm^2) defines the maximum depth of origin above which 63% of the uncollided gammas are seen by the detector. At the outer edges of the detector field of view, the perpendicular depth of the soil for one MFP is approximately one-half of the center line depth. This is due to the increased gamma path length from the point of origination through the soil to the detector. Thus, gamma atten-

TABLE 2

Radionuclides Routinely Measured at the Kellex Site

Isotope	Gamma Energy (keV)	MDA pCi/g	USE
^{241}Am	59.5		Pulse Height Analyzer (PHA) gain calibration
^{234}Th	63.3	8.2	Imply ^{238}U concentration
^{234}Th	92.8	6.1	Imply ^{238}U concentration
^{235}U	185.7		^{235}U and ^{226}Ra appear as one photopeak. They are used to compute ^{235}U and ^{238}U concentrations at secular equilibrium.
^{226}Ra	186.1	2.3	
^{212}Pb	238.6	0.4	Imply ^{232}Th concentration
^{214}Pb	295.2	1.1	Imply ^{226}Ra concentration and ^{238}U activity at equilibrium
^{214}Pb	351.9	0.6	Imply ^{226}Ra concentration and ^{238}U activity at equilibrium
^{208}Tl	583.1	0.6	Imply ^{232}Th concentration
^{214}Bi	609.3	0.4	Imply ^{226}Ra concentration and ^{238}U concentration at equilibrium
^{137}Cs	661.6	0.2	PHA gain calibration - Imply worldwide fallout*
^{228}Ac	911.1	0.6	Imply ^{232}Th concentration*
^{214}Bi	1120.4	1.4	Imply ^{226}Ra and ^{238}U concentrations for secular equilibrium*
^{60}Co	1333.3		PHA gain calibration
^{40}K	1460.8	1.6	Imply ^{40}K concentration*

*Gamma penetration of the shield begins to be significant above 600 keV. Therefore, the area viewed by the detector is not clearly defined above 600 keV.

uation by the soil limits the depth to which gamma emitting radionuclides may be measured. The maximum depths at which 63% (1 MFP) and 95% (3 MFPs) of a uniform distribution of gammas can be measured are indicated in Figure 3.

Exposure Computation -- It is possible to convert the measured concentrations to exposure rate using the tables of Beck et al (1). The contributions from each species and series of radioactive isotopes are summed to provide an estimate of the total gamma exposure at a 1 m height above the ground surface.

EBERLINE INSTRUMENT CORPORATION (Eberline)

Eberline provided project radiological health physics support. This ranged from soil sampling and instrument survey teams to site health physics for personnel protection. Eberline personnel were individually assigned specific tasks such as data recorder, instrument maintenance, soil sampler, etc., to accomplish an efficient and productive program. Additional personnel were added as required to meet the project time schedule. Field data collected by Eberline personnel were recorded and any aromalous areas that were discovered were noted and the locations communicated to the other contractors for further examination. Soil samples were shipped on a daily basis in order to ensure that continuous data would be provided by the analytical laboratory about the site radiological condition. Field instruments, calibrations and site health physics considerations are discussed in the following sections.

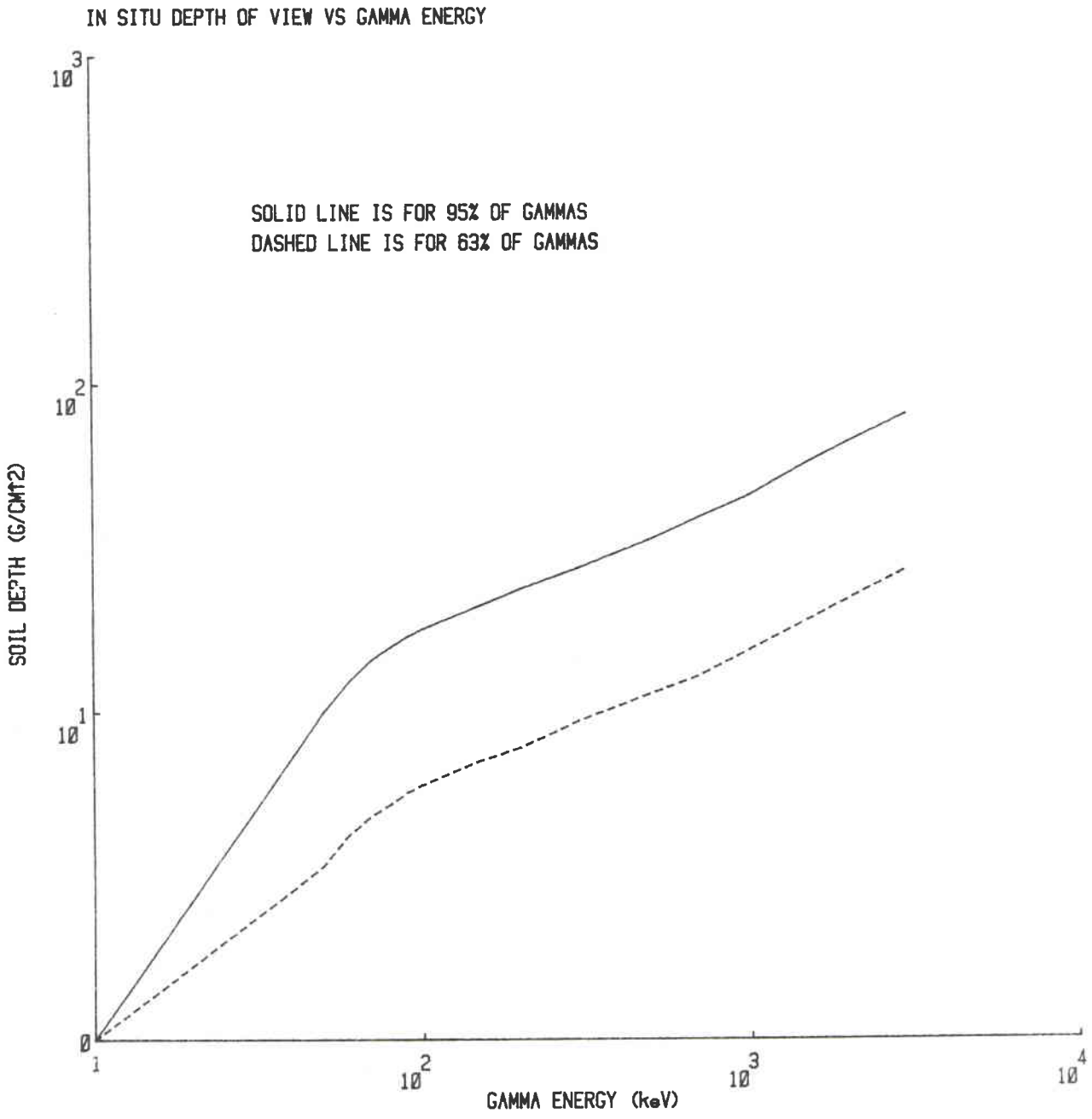


Figure 3. In Situ Depth of View vs. Gamma Energy. The minimum depths from which 63% and 95% of gammas originate as seen by the intrinsic germanium detector used at Kellex.

Field Instruments -- Instrument surveys were made on all trench sidewalls and bottoms for gamma and beta radiation using the three types of portable survey meters which are described below.

a. Gross Gamma Scintillation Meter (SPA-3)

A SPA-3 scintillation probe assembly containing a 5.08 cm diameter by 5.08 cm long NaI(Tl) crystal coupled to a 5.08 cm diameter photomultiplier tube was used to measure low-level gamma radiation exposure. Readout was provided by a digital rate meter-scaler Eberline Model PRS-1 used in the rate meter mode with readout in microreontgen per hour (μR/h) using a calibration factor of 1000 CPM/μR/h. The probe and instrument were adjusted so that a 60 keV ^{241}Am gamma ray would produce maximum counts just above the threshold setting.

The calibration factor was determined by comparing readings with a Reuter-Stokes pressurized ion chamber over a natural uranium source at 1 meter. The response of the SPA-3 is energy dependent but cross calibration with the pressurized ion chamber tends to minimize errors in this measurement which could approach ± 25%.

Recorded μR/h SPA-3 readings listed in this report are the average of two instrument compute cycles after the probe was stationary and in contact with the sidewall or object being measured. Each compute cycle consisted of 1000 counts divided by the time required to collect the 1000 counts. The two readings were typically within 3% of each other. Daily response checks were made using a ^{241}Am standard in contact with the probe face. Instrument response checks and background readings were made from October 21, 1980 thru November 7, 1980 and are recorded in Table 3. All readings were taken over a concrete pad at grid point (GP) (170,80). (See Figure 4).

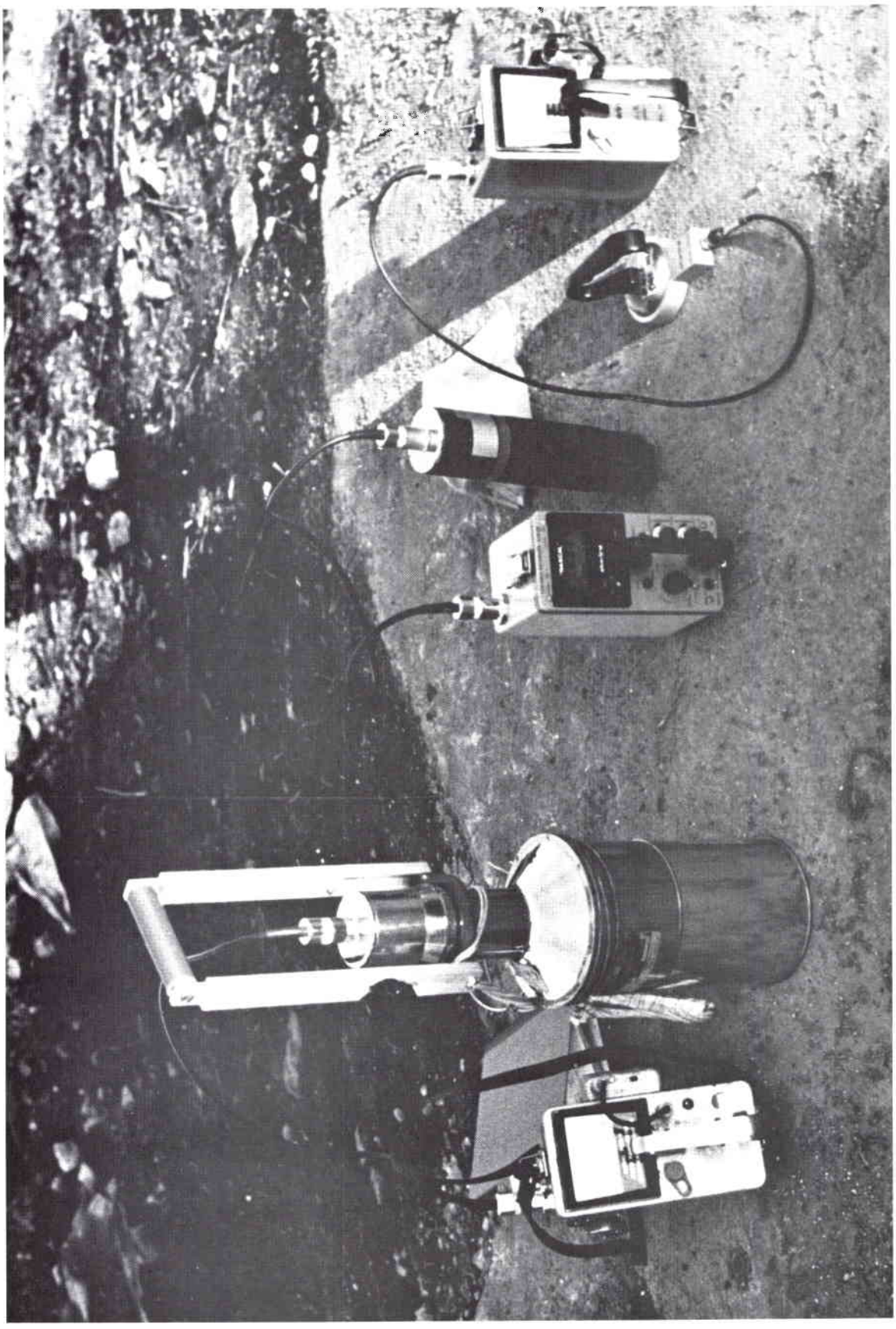


Figure 4. The Eberline Survey Meter Instruments.

b. Beta/Gamma GM Detector (HP-210)

Beta readings were taken using an Eberline HP-210 Thin Mica Window (1.2-1.4 mg/cm^2) GM Tube detector with 15.5 cm^2 surface area mounted in a high density tungsten shield holder. Count rate readout was provided by an Eberline PAC-4S analog rate meter using an SK-1 audio speaker. Readout was in counts per minute (CPM) into probe face with calibration provided by an electroplated ^{99}Tc standard. Average calibration efficiency was 0.28 CPM per DPM into probe face for beta energy of 0.29 MeV maximum. To increase the probability of detecting the 6-8 MeV alphas present with ^{238}U and daughter products, additional window thickness was not added to reach the normal 7mg/cm^2. Typical daily calibration and background readings are shown in Table 3. Also the HP-210 is relatively insensitive to gamma photons as compared to beta particles and since beta particles of 0.29 MeV maximum will penetrate only a few millimeters of soil, this instrument is only suitable for detection of surface contamination.

c. PHA Mode Gamma Scintillation (FIDLER)

A large area NaI(Tl) detector, Eberline RD-21, using a 12.7 cm diameter by 1.6 mm thick crystal coupled to a 12.7 cm long photomultiplier tube with a 0.25 mm beryllium window was utilized to detect the 93 keV gamma ray produced by the ^{234}Th daughter of ^{238}U. To avoid window damage a wire holder was used to keep the detector at least 5 cm from the measured surface at all times. Readout in CPM was provided by an Eberline analog rate meter, Model PRM-5, with SK-1 audio speaker output. The response of the FIDLER (Field Instrument for Detecting Low Energy Radiation) was maximized using a one-half gallon metal can of Kellex soil from GP (55,110) known to contain an average of 150 pCi/g (wet) ^{234}Th.

No absolute calibration of CPM to pCi/g was necessary since the instrument was used to indicate levels higher than background during the trench sidewall scans from which soil samples could be taken for analysis. Average daily response and background readings are listed in Table 3.

TABLE 3

Average Instrument Response and Background Checks for the Portable Survey Instruments.

	SPA-3		FIDLER				HP-210	
Date	^{241}Am μR/h	BKG μR/h	^{241}Am CPM	Kellex soil CPM	Blank-can CPM	BKG CPM	^{99}Tc CPM	BKG CPM
10-21-80	30	NR*	1800	NR	NR	NR	2000	NR
10-22-80	28	6	1500	NR	NR	1500	1900	200
10-23-80	28	6	1300	NR	NR	1200	2000	200
10-24-80	27	6	1200	NR	NR	1000	1800	150
10-27-80	30	8	1800	NR	NR	1700	1800	150
10-28-80	29	8	1800	NR	NR	1800	1900	100
10-29-80	27	6	NR	2000	1200	1400	1900	100
10-30-80	28	6	NR	2000	1200	1300	1800	100
10-31-80	28	6	NR	2000	1200	1400	1800	100
11-01-80	27	6	NR	2000	1200	1400	1900	150
11-03-80	28	6	NR	2000	1100	1400	1900	100
11-04-80	27	6	NR	2400	1200	1400	2000	100
11-05-80	27	6	NR	2200	1300	1500	2700	100
11-06-80	26	6	NR	2000	1200	1400	2400	100
11-07-80	27	6	NR	2400	1300	1600	2000	100

*No reading

Site Health Physics Support -- The health physics program served to document that personnel did not receive external or internal radiation exposure above background levels during the subsurface investigation. Project personnel were required to wear a thermal luminescent dosimeter (TLD) badge while working on site and give a pre-and post-survey urine sample for bioassay. As an additional measure for health physics safety, air samplers were run during working hours so radionuclide air concentrations could be determined.

Twenty personnel TLD(s) and six TLD area badges were placed or issued during the period from October 18, 1980 thru November 8, 1980. They indicated no reading above the background of 2 $\pm$ 0.3 mRem/week.

Thirty pre-and post-survey urine samples were analyzed for total uranium by the fluorometric method with no result greater than the minimum detectable activity of 5 µg/l, for a 24 hour sample.

Air sampling consisted of four positive displacement samplers (Eberline RAS-1 units) drawing air thru 47 mm filter papers at 50 liters per minute. The samplers were used in conjunction with portable generators and were placed at various locations about the site depending upon weather and working conditions.

One sampler was placed permanently at the office trailer complex and ran continuously. The other three samplers were operated during working hours and positioned along site boundaries or around working areas. High and low volume samplers were operated intermittently on the backhoe to assess the dust levels at the operators' position. Air filters were changed at the beginning of each work day with operating time and flow rate recorded for analysis. Initial air filter papers were analyzed for gross alpha at the Middlesex project office, after decay of radon and thoron daughter products, using an Eberline SAC-4 alpha scintillation counter. All samples were returned to Eberline Albuquerque Laboratory for composite analysis by wet chemistry for isotopic uranium and isotopic thorium. All field gross alpha

counts of air sample filters were less than one millionth of the ERDAM 0524 appendix concentration guide allowed for 40 hour occupational exposure.

Composite filter analysis results are reported below.

KELLEX AIR FILTER COMPOSITE RESULTS

Isotope	CG Air (µCi/ml, insoluble)	Office Trailer (µCi/ml)	Workplaces (Sum of other Samplers, µCi/ml)
^{234}U	1.10E-10	<8.8E-16	<3.5E-16
^{235}U	1.10E-10	<2.7E-16	<1.1E-16
^{238}U	1.10E-10	<6.8E-16	<2.2E-16
Total Volume (m^3)		1389	1689

All earth moving equipment and vehicles used on site were washed down, surveyed and swipe tested before release to offsite. No activity above background was detected on any items moved offsite during the project.

Desert Research Institute (DRI) -- DRI provided statistical support as required, which included the design of the subsurface sampling plan and data base management functions. In addition, operational field support was provided for the selection of trench locations, radiological measurement locations and assistance in decisions for various trench and sampling modes triggered by field results.

Development of Subsurface Sampling Plan -- Since the surface survey could detect contamination only in the first several centimeters of soil, subsurface data were needed to get a more complete picture of the radiological condition of the site. It was felt that digging one meter deep trenches on the site would best accomplish this since trenching deeper would probably encounter the ground water table.

Two experimental trenches were dug to determine what difficulties would be encountered and the proper equipment to use. One trench was dug in an area of suspected contamination as suggested by the surface survey, and the other in an area where surface measurements indicated background levels. A backhoe was used to dig each trench and then place the removed material on one side of the trench. After the spoil was spread, it was surveyed by the in situ measurement system. It was determined that spoil piles dug could be spread no more than 10 m because of the volume of material removed from the trench. However, in areas where contamination was suspected, soil piles would only be spread five meters to avoid interference with nearby trenches. Although some digging difficulty was encountered, it was concluded that trenching was the most desirable method for subsurface characterization.

To locate physical obstructions to trenching, the site was "walked" and obstructions were plotted. To aid in this, photographs of the original plant and the present day site were studied. The results of the surface characterization provided further input for specifying the location of trenches.

To attain a high degree of confidence of locating an area of contamination which would cause the guideline to be exceeded, trenching was done at a 5 m spacing in suspect areas. This spacing gives a probability of .85 of detecting a contaminated disk of eight square meters (see Appendix B). This calculation is based on a previous investigation that recorded a 2,000 pCi/g of ^{238}U at one location. The spacing increased to 10 m as the distance from suspected contamination became greater. In areas where contamination was not suspected, trenches were dug intermittently at a 20 m spacing. The initial locations of trenches are plotted in Figure 5. From this figure the total length of trenching was estimated to be approximately 2,600 meters.

To gain maximum information about the subsurface soil, the sidewalls of the trenches were surveyed by Eberline with field instruments and profile soil samples taken at grid nodes.

With the sampling plan developed, estimates of the approximate number of soil samples and in situ measurements could then be calculated. In addition, project completion time could be estimated.

Data Base and Equipment -- Data collected by the in situ measurement system was transferred to a magnetic disk using a Hewlett Packard 9381A computer. By doing this a backup copy of data was created and quality assurance could be done. These data and Eberline field results and soil sample analyses will be transferred to a 9-track magnetic tape for long term storage at DOE/NV. Additional computing equipment included a plotter and printer for displaying and summarizing data as necessary.

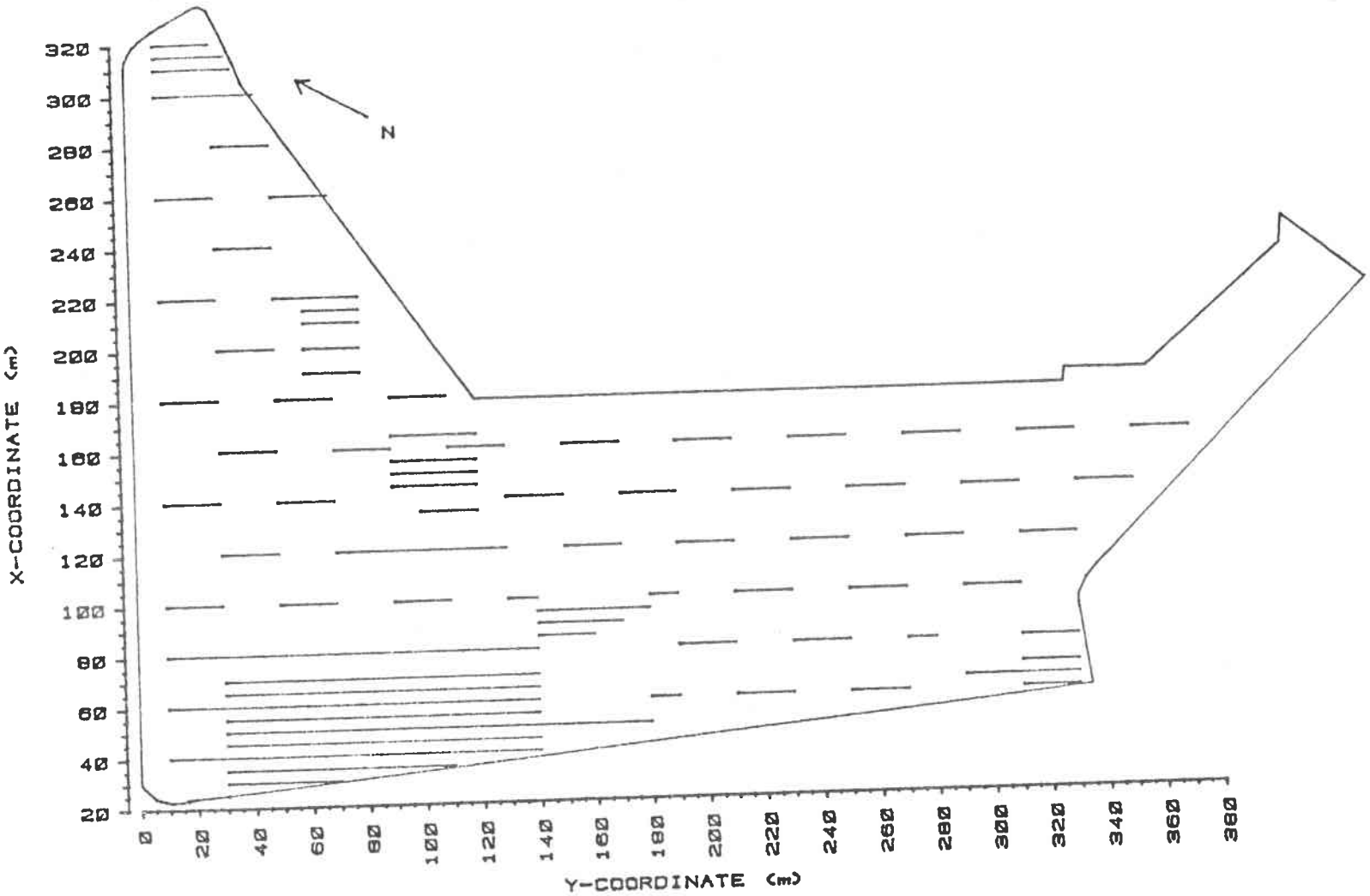


Figure 5. The Pre-survey Trench Locations.

Operational Procedures

Sampling Decisions -- For this radiological subsurface and surface survey, constant decision-making was necessary to determine whether additional sampling was needed. Making the decision in the field was more feasible than waiting for the results of soil sampling analysis in order to decide if additional trenching was required. Therefore, the in situ measurement system was relied upon to make such decisions. If both 63 keV and 93 keV peak of ^{234}Th indicated activity greater than MDA, this was an indication that further examination in that area was warranted. This gave a detection limit of approximately 6-8 pCi/g of ^{234}Th when using a 15 minute acquire time. This also assumes that uranium is in secular equilibrium with its daughters. Furthermore, it was recognized that this trigger does not necessarily imply the presence of excess ^{234}Th, but it was used as a guideline for sampling decisions. A decision during surface characterization to investigate an area further resulted in establishing a 5 m grid around the location, and taking measurements with the IG detector at a lower height. A "look closer" decision for the subsurface survey meant trenching on either side 5 m away, taking additional measurements and collecting soil samples.

The Kellex Grid System -- A grid system was surveyed and staked by Ford, Bacon and Davis of Utah, Inc. This system was subsequently tied to the New Jersey state coordinate system by Fisk Associates of Middlesex, New Jersey.

The grid was square with stakes at 20 m intervals (Figure 6). The x-axis runs in an north-easterly direction and lies on the south edge of the concrete along Droyers Street. The y-axis extends in a south-easterly direction in the parking lot across Droyers Street from the Kellex site. The grid tie points with the New Jersey coordinate system are listed below.

NEW JERSEY COORDINATES OF THE 20 m GRID SYSTEM

20 Meter Grid		New Jersey	
X	Y	N (ft)	E (ft)
0	0	684,334.45	2,155,434.48
140	0	684,453.01	2,155,878.39
300	0	684,588.67	2,156,385.48

A large subsection of the site was gridded on 5 m intervals by Ford Bacon and Davis of Utah because it had the highest probability of containing contamination. This area is defined by the GP (70,35), (70,140), (35,35) and (45,40). Additional locations where a 5 m grid was needed were measured by field personnel using established grid nodes (Figure 7).

DATA COLLECTION

Surface -- Before the surface survey began, a general site physical cleanup was necessary. Tall weeds were cut down and loose rubble was piled. The large piles of concrete rubble were not moved at this time in order to minimize soil disturbance. Backdragging was also kept to a minimum for this same reason. After site preparation was completed, the previously described 20 m and 5 m grid were established.

In situ measurements were then taken on the 20 m and 5 m grids (Figures 6 and 7).

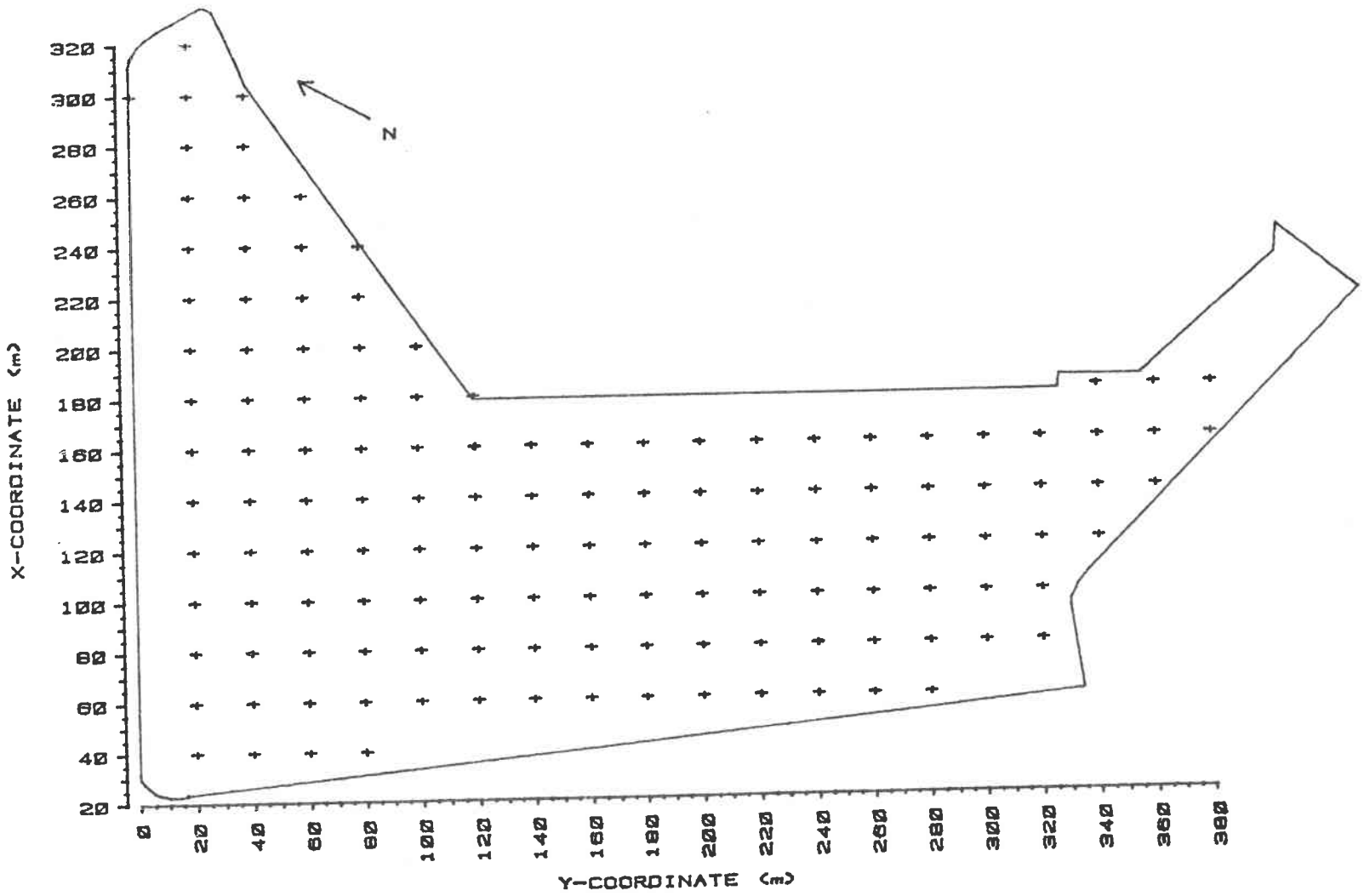


Figure 6. The 20 m Grid.

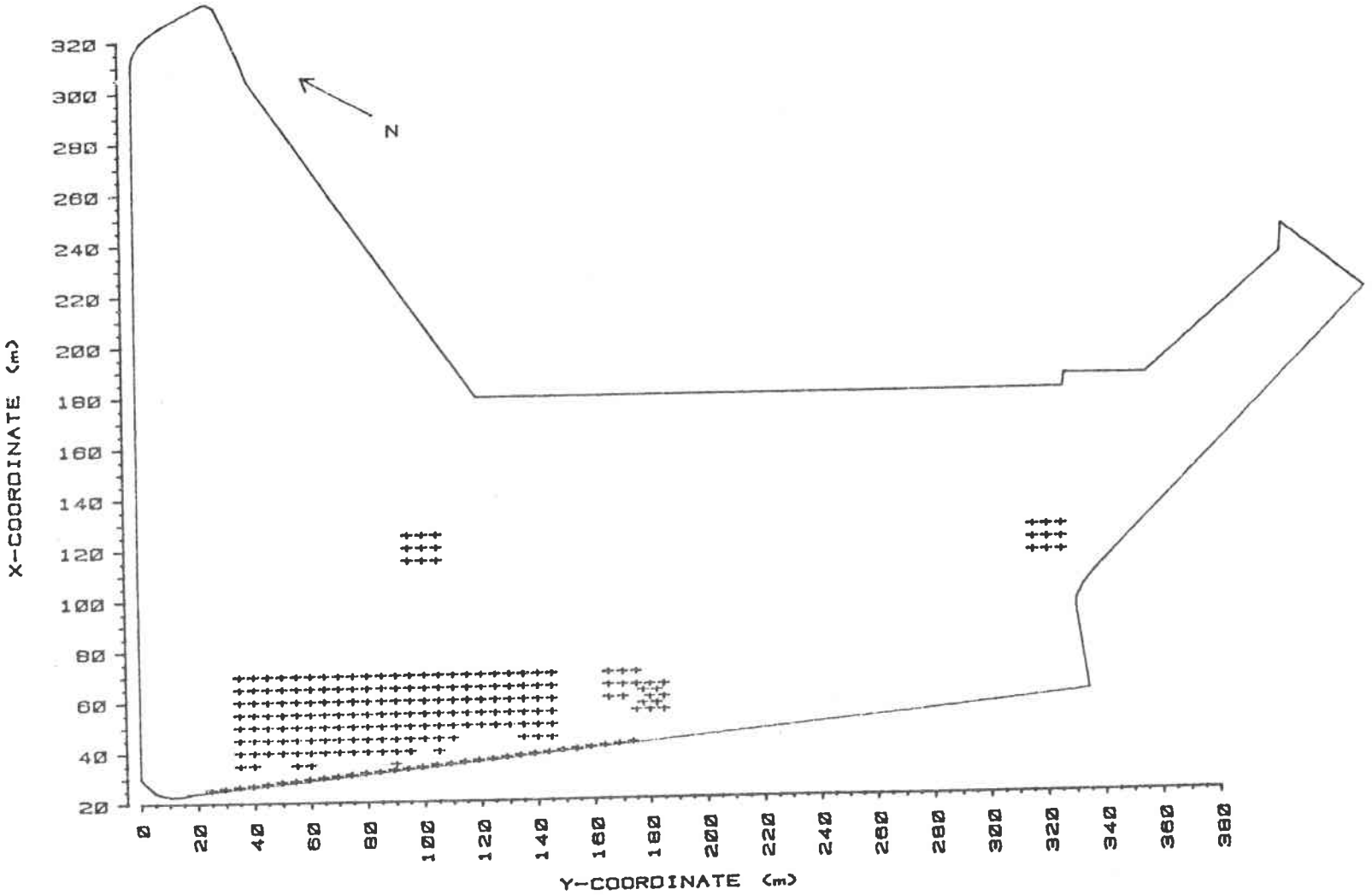


Figure 7. The 5 m Grids.

Subsurface Data Collection -- Because the trenching operation destroyed the grid as it progressed, trench centerlines were lined with chalk prior to digging. Locations for soil samples and in situ measurements were chalked as hash marks but on the opposite side from the spoil pile. In this manner locations recorded by data collection teams would be consistent.

As each trench was dug, the Eberline instrument team would move in and survey the sidewalls and bottom using the instruments described earlier. At each grid node marked, instrument readings were made and recorded at 5 cm, 15 cm, 25 cm, 45 cm and 75 cm depths using a pre-marked measuring stick as a guide. Additionally the trench bottom readings were recorded for each grid location but were not reported in the data listings unless the readings exceeded the sidewall values. If scan instrument readings exceeded the values recorded at the grid nodes, additional "bias" sample nodes were marked and recorded. All scan instrument readings between grid nodes were taken using the audio output generated by the detector as a level detection method. All grid nodes were taken using a pause and read technique to reduce the instrument response error factor. All old laboratory debris, sewer pipes and concrete slabs uncovered were scanned for possible contamination.

A 1500 g soil sample was taken from each grid and "bias" sampling point at 5 cm, 15 cm, 25 cm, 45 cm and 75 cm depths using a drive type sidewall sampler tool and placed in plastic bag lined 1/2 gallon metal cans. Sample grid location, date and depth information was embossed on an aluminum label fixed to the cans.

Field samples were packaged in preformed cardboard boxes and shipped to the Eberline Midwestern and Albuquerque laboratories for prompt Ge(Li) scanning to provide correlation with field instrument readings.

As the trenching progressed it was discovered that the location of a trench often had to be shifted to one side or the other to facilitate digging. This shifting was caused by the large number of obstructions found either before trenching or after digging had begun. Pilings, foundations and soil covered concrete pads made digging trenches extremely difficult in parts of the site. Locations of all trenches dug are shown in Figure 8.

Similar problems occurred with soil sampling and monitoring at prescribed depths. Often sidewalls were not perpendicular making precise depth location difficult. It was also difficult to collect soil samples when "soil" was actually concrete chunks or clay bricks.

Holes created by the previous clean-up had been filled with large chunks of concrete rubble. These were simply bulldozed away in order that trenching could go through that area.

When an in situ measurement of a spoil pile indicated the need for additional data in an area where trenching spacing was not 5 m, additional trenches were dug 5 m on either side of the location. If the additional measurements made at these trenches indicated no further sampling then trench spacing was increased to the original interval. This was done to better define areas that might exceed the guideline or be of concern in the future.

The depth of a trench was kept as close to one meter as reasonable, but digging with a one cubic yard bucket meant 1% accuracy was not feasible. During high tide it was not unusual for the lower 5-7 cm of the trenches to fill with water. However, to gain additional knowledge about the radiological character of the soil, a section of two trenches was dug down to groundwater level, about 2 m.

A total of 71 trenches were dug ranging in length from 5 m to 177 m. The total length of trenches was 2,218 m or approximately 1.4 miles. There were 328 in situ measurements of the spoil piles and 1634 soil samples taken.

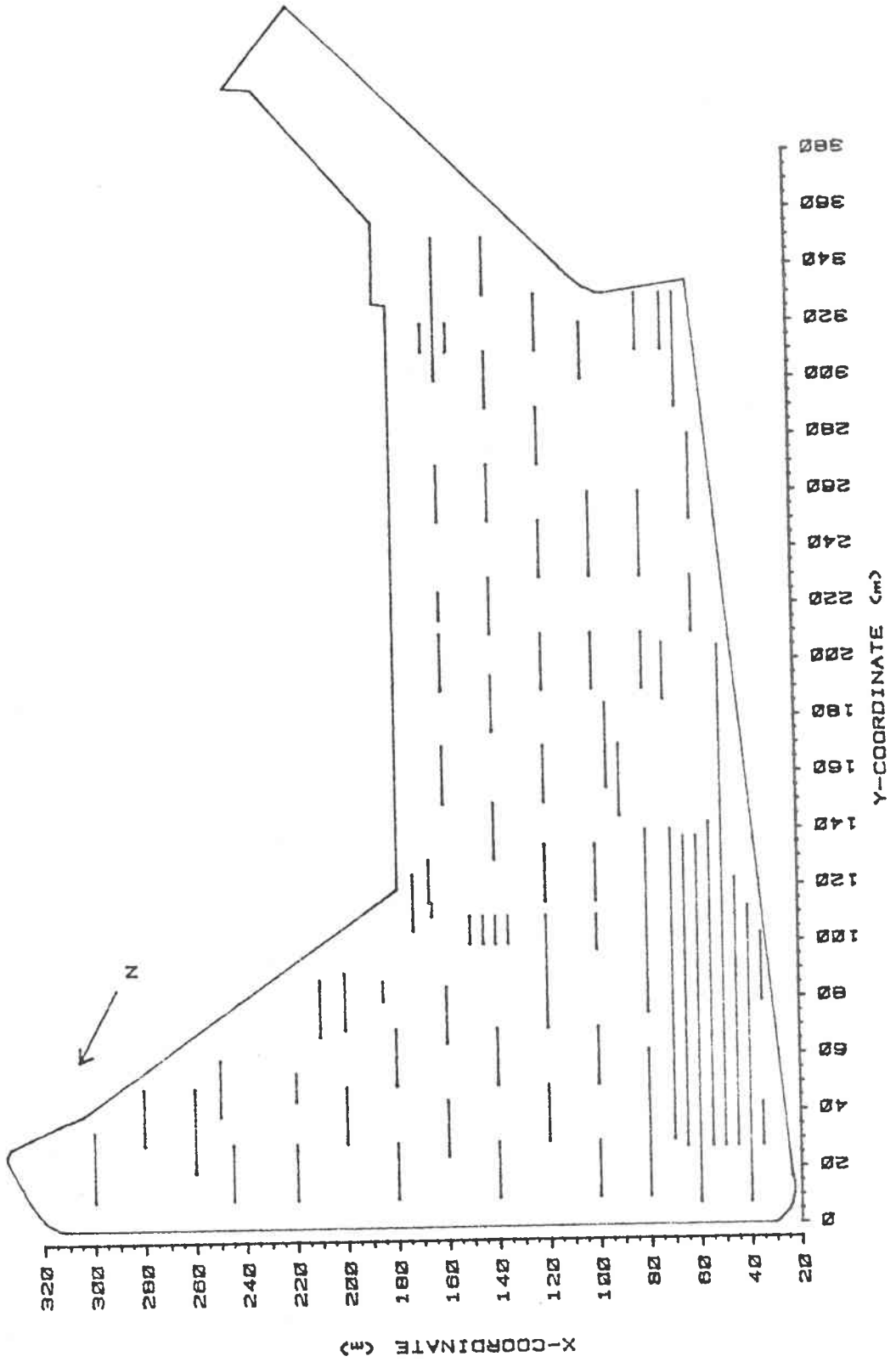


Figure 8. Actual Locations of Trenches.

POST SURVEY ANALYSIS

In Situ Gamma Data Analysis -- Subsequent to the survey an analysis was done on the total data base. The analysis consisted of:

1. Evaluating the means and standard deviation of the concentration for each of the isotopes investigated.* Those measurements thought to represent anomalies in the ^{234}Th concentration (greater than MDA) were not used in this computation. The means might be called New Jersey means.

2. Some of the individual concentration values from individual photopeaks (for a 15 minute measurement) were pooled to produce mean values with smaller MDA. Those pooled were (a) ^{234}Th (E=63.3 and 93.4 keV), (b) ^{212}Pb and ^{208}Tl (E=238.6 and 583.1 keV), and (c) ^{214}Pb (E=295.2 and 351.9 keV).

3. The same pooled values from each 15 minute measurement were then compared to the respective pooled New Jersey mean plus three times the sample standard deviation. If this pooled value was greater than this quantity then the datum was flagged and recorded for further study and mapping. However, subsurface data were treated slightly different because possible concentrations near the guideline may have been diluted by a factor of 5. So all ^{234}Th concentrations greater than the New Jersey mean plus two times the sample standard deviation were flagged. In this way all anomalies could be discovered in a systematic fashion.

4. Finally all the flagged values were mapped on the Kellex grids (20 m, 5 m and subsurface) for interpretation. (Figures 6, 7 and 8.)

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*^{226}Ra activity calculations using the 186 keV photopeak were based on the assumption ^{238}U was in secular equilibrium with ^{226}Ra. No attempt has been made here to separate the ^{226}Ra component from the ^{235}U component in the 186 keV photopeak when ^{238}U is not in equilibrium with ^{226}Ra.

Laboratory Analysis

1. Gamma Spectrometry - Soil samples were weighed and placed in 500 cc containers. These containers were placed on Ge(Li) detectors with relative efficiencies of 20% for a count time of 20 minutes. This count time gave a lower detection limit of 2.5 pCi/g for ^{226}Ra and 10 pCi/g for uranium.

Calculating activity in pCi/g was found by using the equation:

$$\text{Specific activity} = \frac{S - B}{W \times M \times E \times A \times CF} \quad \text{pCi/g}$$

where S = Sample count
B = Background count
E = Efficiency
A = Abundance
W = Weight (g)
M = Count time (minute),
CF = 2.22 dpm/pCi, a conversion factor and

the percent error is $\frac{(S + B)^{1/2}}{S - B}$ 100.

The constant 2.22 dpm/pCi is a conversion factor relating dpm to pCi.

The lower limit of detection (LLD) is:

$$LLD = \frac{4.65\ S_B^*}{E \times A \times W \times M \times CF} \quad \text{pCi/g}$$

where S_B is standard deviation of background.

Both ^{226}Ra and uranium were quantified by assuming their daughters were in secular equilibrium (^{214}Pb and ^{214}Bi for ^{226}Ra and ^{234}Th for uranium).

2. Alpha Spectrometry - A sample which received wet chemistry analysis was weighed, ball milled, and ten gram aliquots were transferred to teflon beakers. Samples in the beakers were treated with nitric, hydrochloric and hydrofluoric acids and the acid leach separated from the residue by filtering.

*For a discussion of this term, refer to (3).

The sample leach was taken through specific chemistries required to extract thorium, uranium, and radium for counting in an alpha spectrometer.

Isotopic activity in pCi/g is estimated by:

$$\frac{N_1}{N_2} \times \frac{C}{W}$$

where N_1 = net counts of isotope
N_2 = net counts of tracer isotope
B = Background count
M = Count time (minute)
C = pCi Tracer added
W = Weight (Aliquot g)

and the sample fractional variance is given by:

$$\frac{1}{N_1} + \frac{1}{N_2} .$$

The lower limit of detection is:

$$LLD = \frac{4.65\ S_B}{E \times Y \times M \times W \times CF} \quad pCi/g$$

where E = Efficiency
Y = Yield (recovery)
M = Count time (minute)

3. Radon Deemanation - ^{226}Ra is calculated by radon emanation and is found by:

$$\text{Activity pCi/g} = \frac{S - B}{M \times C \times I \times D \times Y \times W}$$

where

C = Calibration factor in cph/pCi
S = Sample count
B = Background count
I = Ingrowth factor of ^{222}Rn
D = Decay factor of ^{222}Rn
Y = Yield
M = Count time (h)
W = Aliquot (g)

RESULTS

In Situ Data -- The New Jersey mean concentrations together with the concentrations measured by Berven et al (2) are listed in Table 4. There are several significant interpretations from this table:

1. The in situ means agree quite well with Berven's New Jersey Kellex means.

2. The means do not change from surface to subsurface.

3. The ^{234}Th (^{238}U) concentration is larger than that of ^{226}Ra which indicates disequilibrium between ^{238}U and ^{226}Ra.

4. ^{226}Ra appears to be in equilibrium with its daughters so radon emanation may be small.

5. The exposure computed from these mean values on the 20 meter grid is 6.8 μR/h which compares well with the 7 μR/h obtained by Berven (2).

Data in tables for ^{226}Ra was calculated from the 186 keV photopeak. This calculation assumed secular equilibrium of ^{238}U and ^{226}Ra. Furthermore, there was no attempt to separate the ^{226}Ra component from the ^{235}U component.

TABLE 4

New Jersey Mean Potassium, Uranium and Thorium Concentrations
From Kellex Data (Units in Mean ± Sample Standard Deviation - pCi/g)

Radionuclide	Energy (keV)	5m Grid	20m Grid	Subsurface	Berven*
^{234}Th	63.3	2.07 ± 2.9	2.31 ± 3.4	1.86 ± 2.8	1.8
^{234}Th	93.4	1.98 ± 2.3	1.76 ± 2.2	2.09 ± 1.9	1.8
^{226}Ra	186.1	1.12 ± 0.9	0.99 ± 0.9	1.10 ± 0.9	1.2
^{212}Pb	238.6	1.12 ± 0.4	1.08 ± 0.4	1.12 ± 0.4	1.1
^{213}Pb	295.2	1.17 ± 0.6	1.27 ± 0.7	1.21 ± 0.5	1.2
^{214}Pb	351.9	1.20 ± 0.6	1.21 ± 0.5	1.23 ± 0.4	1.2
^{208}Tl	583.1	1.07 ± 0.6	1.13 ± 0.5	1.09 ± 0.4	1.1
^{214}Bi	609.3	1.19 ± 0.6	1.18 ± 0.5	1.20 ± 0.4	1.2
^{228}Ac	911.1	0.97 ± 0.6	1.00 ± 0.5	1.02 ± 0.4	1.1
^{214}Bi	1120.4	1.23 ± 0.9	1.24 ± 0.8	1.29 ± 0.7	1.2
^{40}K	1460.8	7.56 ± 1.8	8.38 ± 2.0	8.13 ± 1.9	
		Pooled Means			
^{234}Th	63.3				
	93.4	2.02 ± 2.0	1.93 ± 1.9	2.01 ± 1.6	1.8
^{214}Pb	295.2				
	351.9	1.20 ± 0.6	1.22 ± 0.5	1.23 ± 0.4	1.2
^{214}Pb &	295.2				
^{214}Bi	351.9				
	609.3	1.20 ± 0.6	1.20 ± 0.5	1.21 ± 0.4	1.2
^{212}Pb &	238.6				
^{208}Tl	583.1	1.10 ± 0.4	1.09 ± 0.3	1.11 ± 0.4	1.1

*The Berven results are implied, the others measured.

20 m Grid - In Situ Results -- For the 20 m grid measurements the following locations had the greatest estimated concentration of the listed radionuclides.

	GP Location		Concentration
Radionuclide	x(m)	y(m)	pCi/g
^{234}Th	40	80	8.8
^{226}Ra	60	220	3.3
^{214}Pb	100	40	2.5
^{212}Pb & ^{208}Tl	120	320	2.1
^{212}Pb & ^{208}Tl	100	20	2.1

Those 20 m surface grid locations with concentrations significantly greater than the New Jersey mean for ^{234}Th are listed in Table I of Appendix C and plotted in Figure 9.

5 m Grid - In Situ Results -- Listed here are the maximum concentrations measured on the 5 m grid together with their locations.

	GP Location		Concentration
Radionuclides	x(m)	y(m)	pCi/g
^{234}Th	65	170	27.6
^{226}Ra	50	55	8.6
^{214}Pb	115	325	2.9
^{212}Pb & ^{208}Tl	120	320	2.2
^{212}Pb & ^{208}Tl	115	105	2.2

The plot (Figure 10) of this data does show some structure. Two or more of the radionuclides investigated generally occur together. The areas showing concentrations significantly greater than the New Jersey means are generally grouped together along the x = 40 to 65 line and for y values from 80 to 125 meters.

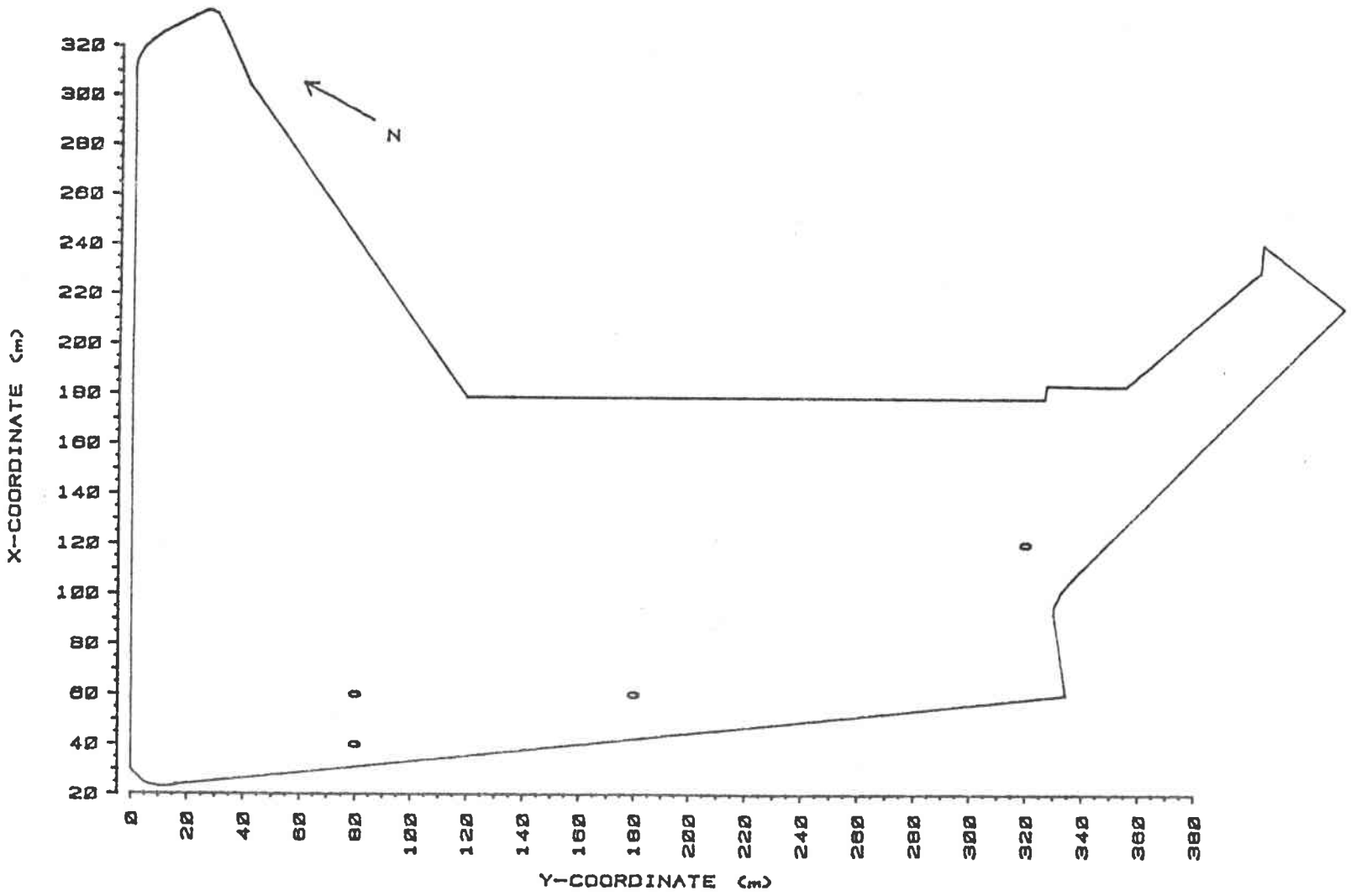

Figure 9. 20 m Grid In Situ Measurements. Locations having ^{234}Th concentrations significantly greater than New Jersey mean level at Kellex.

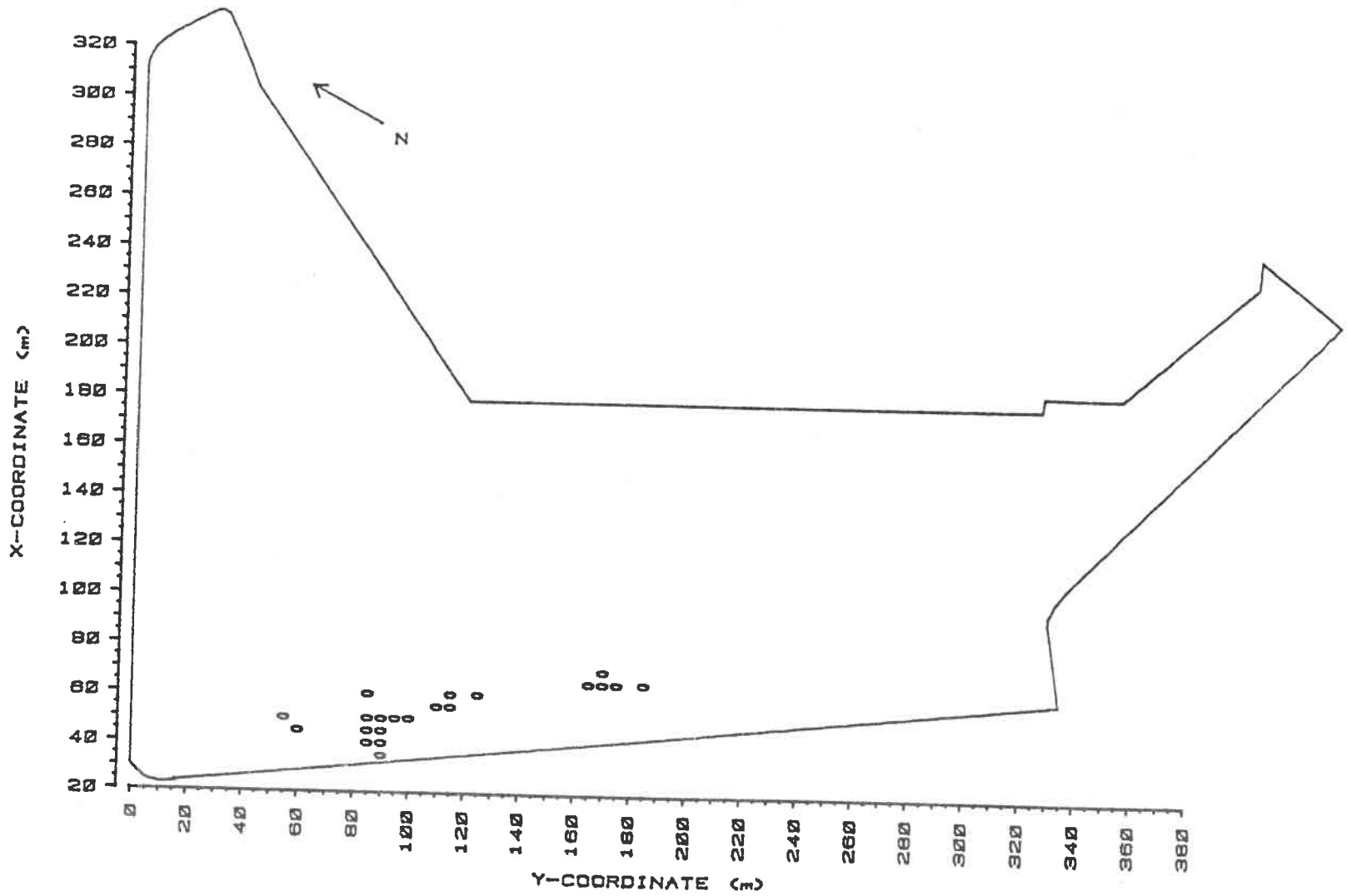

Figure 10. 5 m Grid In Situ Measurements. Locations having ^{234}Th concentrations significantly greater than New Jersey mean level at Kellex.

This behavior was expected from the data of Berven et al (2) and is probably connected with operations at the Kellex plant. See Table II in Appendix C for radionuclide concentration of these locations. The locations plotted are for ^{234}Th only but elevated concentrations of ^{226}Ra generally occurred at the same locations. The ^{226}Ra concentrations were assumed to be a result of ^{235}U gammas which occur in the ^{226}Ra photopeak. No ^{214}Pb concentration, a daughter of ^{226}Ra, was significantly greater than the New Jersey mean which supports this assumption.

Subsurface Results -- Locations of maximum concentrations found during the subsurface survey are given here for several radionuclides.

Radionuclide	GP Location x(m)	GP Location y(m)	Concentration pCi/g
^{234}Th	35	90	21.8
^{226}Ra	45	55	5.4
^{226}Ra	35	90	5.3
^{214}Pb	80	55	2.4
^{212}Pb & ^{208}Tl	150	108	2.0

The trenched soil shows anomalous concentrations of ^{234}Th and ^{226}Ra in the region x = 40 to 65 m and y = 85 to 110 m as does the surface data and this is probably related to the gaseous diffusion operations. Listed in Table III in Appendix C are the radionuclide concentrations at the locations in Figure 11 which show results above the decision value (>5 pCi/g ^{234}Th). Again, only ^{234}Th locations are plotted since the locations of significant ^{226}Ra concentrations in the table correspond to ^{234}Th (^{238}U).

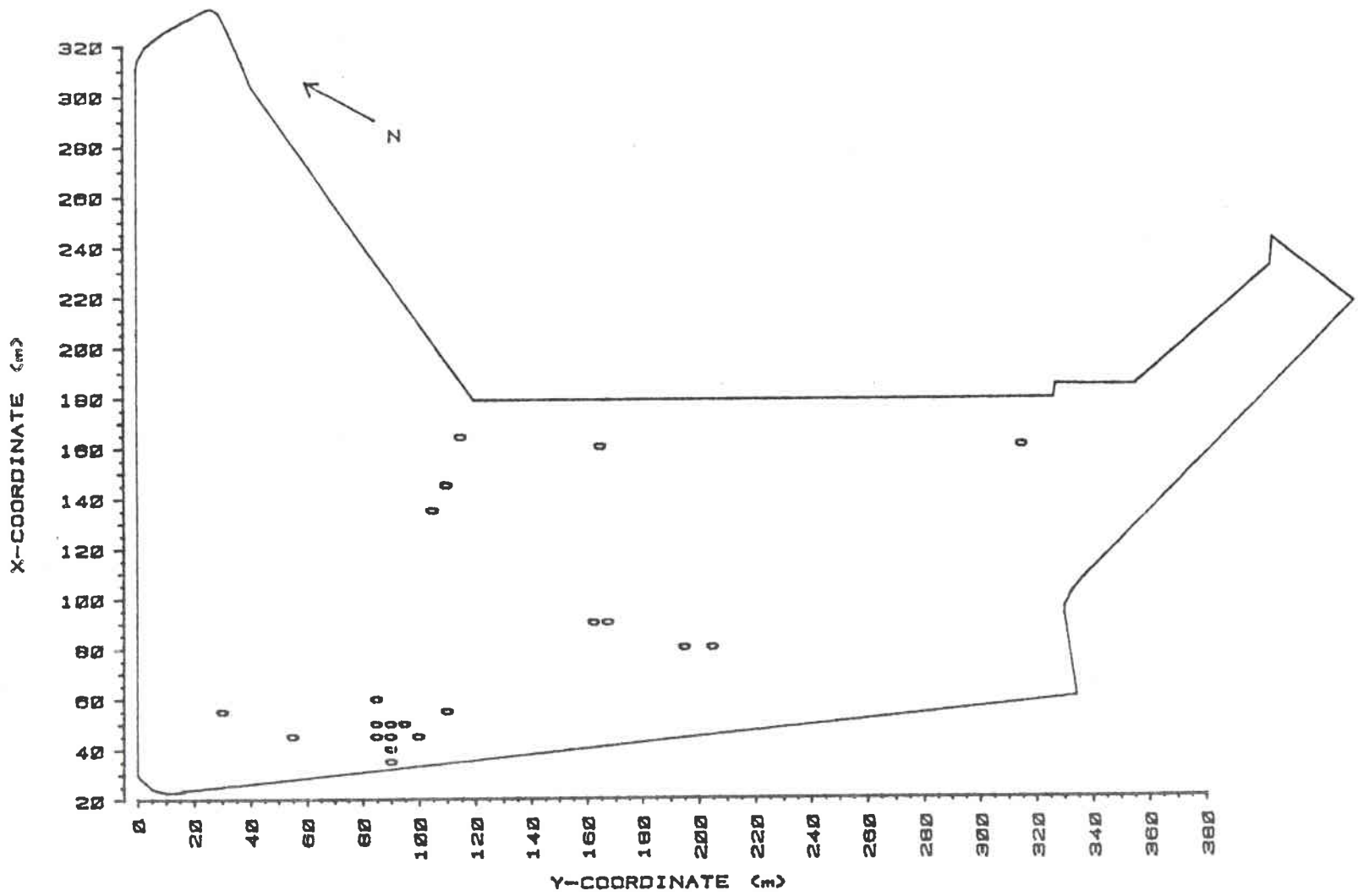

Figure 11. Spoil Pile Measurements. Locations of subsurface soil having ^{234}Th concentration significantly greater than New Jersey mean level at Kellex.

The maximum ^{234}Th concentration was found at GP (35,90). The source of this anomaly was subsequently located by the FIDLER technique at the GP (33,89). This position was confirmed by the in situ measurement system with the detector lowered to .5 m above the ground. The activity appeared to occupy an area of about .3-.6 m in diameter. The depth of the activity is unknown.

This area was not in a trench, but rather beside the trench and resides in undisturbed ground under the former fence line which had been pushed away in order to dig the trench. The tractor in spreading the spoil pile for the in situ measurement, moved some of this activity across the 5 m wide flattened spoil pile.

The spoil pile including the streak of activity was shoved by the tractor back into the trench. A final in situ measurement at GP (35-90) showed a value of 20 pCi/g of ^{234}Th and 11 pCi/g of ^{226}Ra. Neither the ^{214}Pb concentration nor the ^{212}Pb and ^{208}Tl were greater than the New Jersey means so the activity measured was probably due to ^{234}Th (and ^{238}U) and ^{235}U only. That is, the 185 keV gamma from ^{235}U caused the ^{226}Ra anomaly since ^{214}Pb shows no unusual activity.

Eberline Field and Soil Sampling Results -- Instrument scans were used as a method of comparing relative radiation levels of trench sidewalls but not as an absolute calibrated readout of contamination in situ. Geometry factors, instrument response, gamma ray abundance and soil attenuation preclude quantitative or qualitative in situ measurements with full instrumentation.

Field instrument and soil background was established using the trench at GP (300,15) through GP (300,32) which was away from suspected contaminated areas. The following instrument readings were observed in the background trench.

Location GP (x,y)	Depth cm	HP-210 cpm	FIDLER cpm	SPA-3 μR/hr
(300,15)	5	100	1900	9
	15	100	2100	9
	25	100	2500	10
	45	100	2600	13
	75	100	3000	13
(300,25)	5	100	1300	6
	15	100	1300	6
	25	100	1100	7
	45	100	1400	7
	75	100	1300	8
(300,32)	5	100	1800	8
	15	100	1700	8
	25	100	1900	8
	45	100	2000	10
	75	100	2300	10
Arithmetic mean		100	1880	8.8
Sample Standard Deviation*		---	553	2.1

*Sample standard deviation = $\left[\sum_{i=1}^{N} (x_i - \bar{x})^2/n-1\right]^{1/2}$

Analysis of soil samples from these trench locations are listed below:

Radionuclide	Concentration (pCi/g) Ge(Li) Scan	Wet Chemistry
^{234}U		.34 ± .12
^{235}U		<.05
^{238}U		0.4 ± .13
^{228}Th		1.3 ± .3
^{230}Th		0.7 ± .23
^{232}Th		1.3 ± .3
^{234}Th	<10	
^{226}Ra		
^{214}Pb	<2.5	
^{214}Bi	<2.5	
^{40}K	<15	

The values at which "bias" samples would be taken was set at the following instrument levels:

(Background + 3 sigma) x 130%

HP-210 (200^1 + 69) x 1.3 = 350 cpm

FIDLER (1880 + 1600) x 1.3 = 4500 cpm

SPA-3 (9 + 7) x 1.3 = 21 μr/hr

Values for gross instrument readings corresponding to levels greater than 20 pCi/gm ^{238}U were estimated to be: 500-700 cpm for the HP-210[2], 20-25 μR/hr for the SPA-3 and 6000-7000 cpm for the FIDLER.

[1]Based upon daily instrument response readings, a value of 200 cpm was used for background.

[2]The HP-210 is a pancake GM detector which is relatively insensitive to gamma photons as compared to beta particles. Since beta particles of 0.29 MeV maximum will penetrate only a few millimeters of soil, the HP-210 is only suitable for detection of surface contamination.

Bias samples were taken from the following locations that had high readings or were higher than adjacent sampled grid points.

GP (35, 90) - Hot spot on surface near GP (35,90)
GP (65,175) - Concrete pad hot spot
GP (135,110) - > 20 μR/hr SPA-3, 6000 cpm FIDLER
GP (150,109) - " " " "
GP (160,159) - 20 μR/hr, higher FIDLER adjacent area
GP (160,327) - 45 cm depth was higher than adjacent area.
GP (220, 45) - Higher than adjacent area

Three areas found by the instruments to exceed the guideline were also confirmed by laboratory results.

GP (35, 90) Isolated hot spot that was found by in situ system after the backhoe had opened up trench. The maximum concentration by chemistry was ^{234}U 260 $\pm$ 30 pCi/g dry, ^{235}U 7 $\pm$ .9 pCi/g dry, ^{238}U 250 $\pm$ 30 pCi/g dry. Approximate volume estimated to be less than one cubic foot before the tractor spread it out for in situ scan.

GP (55,110) A small isolated hot spot thought to be less than one ft^3 that was found by an instrument on the surface. The maximum concentration by chemistry was ^{234}U 330 $\pm$ 90 pCi dry, ^{235}U 14 $\pm$ 4 pCi dry, ^{238}U 320 $\pm$ 90 pCi dry, ^{230}Th, ^{232}Th were less than 2 $\pm$ 0.5 pCi/g dry.

GP (65,175) The area consisted of brown material on surface of old concrete pad. Maximum concentration by chemistry was ^{234}U 110 $\pm$ 10 pCi/g dry. No

^{230}Th or ^{232}Th data are available. The estimated area of contamination was 6.1 meters square by 0.6 cm deep on the concrete surface. Samples taken under the slab were higher than other areas but less than 8 pCi/g of ^{234}Th.

Locations are listed in Appendix C Table IV where wet chemistry was done to verify higher reading values and for background data.

The following locations were found to have high Ge(Li) scan values for ^{234}Th, but did not have instrument readings that corresponded.

Location GP (x,y)	Depth (cm)	^{234}Th pCi/g (Wet)
(60,110)	0	32 ± 3
(60,115)	5	14 ± 6
(60,115)	15	11 ± 6
(60,100)	5	38 ± 10
(60,100)	15	49 ± 10
(60,100)	25	63 ± 13
(60,100)	45	15 ± 8
(45,100)	5	18 ± 2

The above locations are plotted in Figure 12.

No other location surveyed or sampled had instrument readings or Ge(Li) scan values that indicated soil contamination exceeding our guideline.

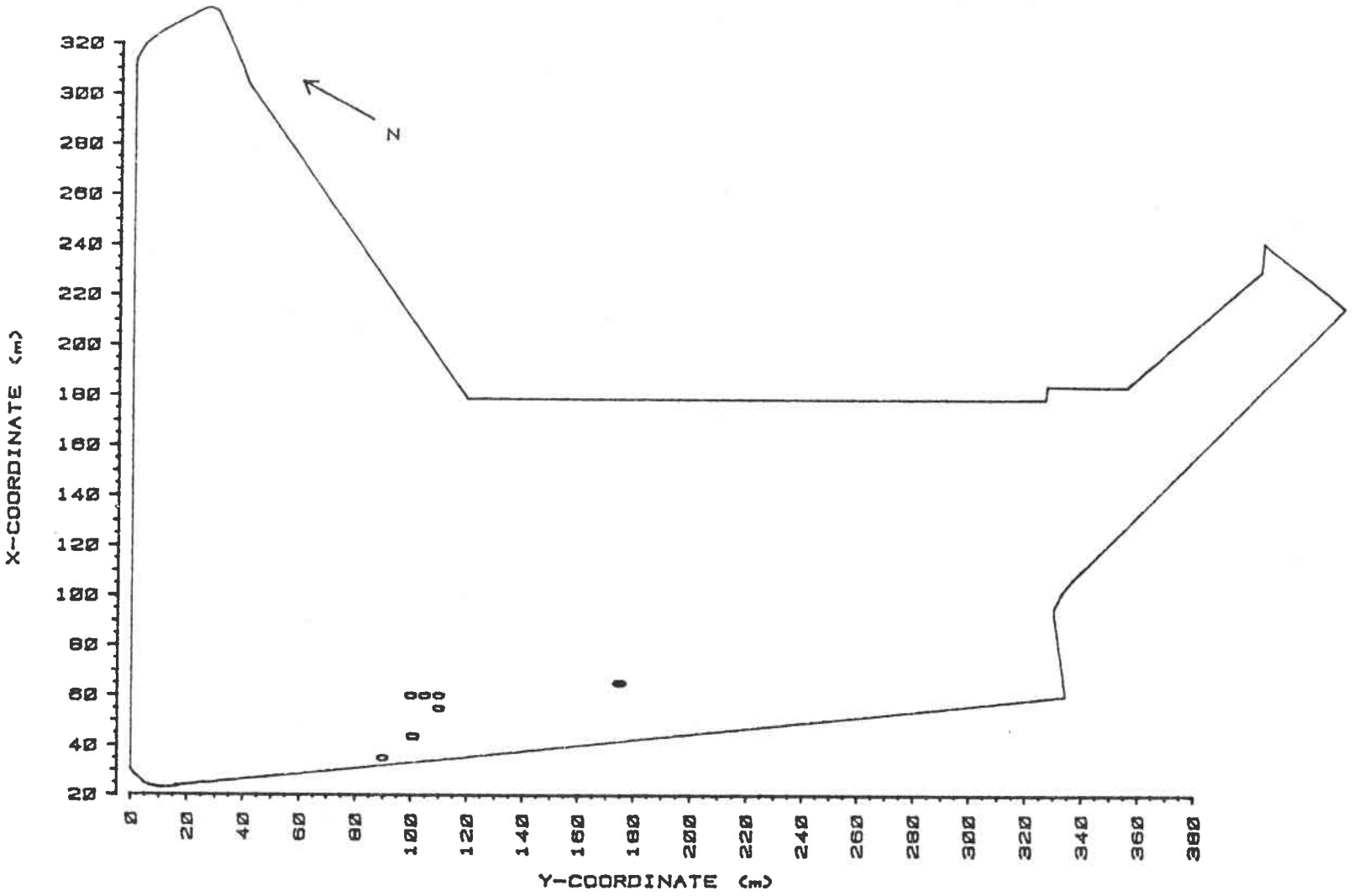

Figure 12. Soil Sample Locations. Soil samples having greatest concentrations of uranium and/or thorium.

CONCLUSIONS AND DISCUSSION

Survey Coverage at Kellex -- The entire Kellex site surface of about 6.2 hectares (15.2 acres) was surveyed on a 20 meter grid pattern with the in situ measurement system. Because the field of view of the IG detector is circular, less than 1% of the surface area was not surveyed. Suspected anomalous areas were surveyed on a 5 meter grid to define more precisely the spatial extent of any anomalies. The subsurface survey included a total of 2128 m of trenching 1 m deep and 160 m wide was dug which represents about 5% of total volume of soil to a 1 m depth at the Kellex site. Furthermore, many underground building and storm drain lines were surveyed and sampled.

Surface -- For the natural gamma emitting nuclides, the general character of the Kellex site is the same as the general character of New Jersey soil. The in situ system indicated one paradox, that ^{238}U and daughter ^{234}Th are somewhat larger than expected compared to ^{226}Ra and its daughters. Table 4 summarizes the mean levels measured.

The anomalous surface areas at Kellex are labeled in detail in Figures 6 and 7 and in Tables I and II in Appendix C. The radionuclide ^{234}Th (the immediate daughter of ^{238}U) showed the greatest deviation from the New Jersey mean. Its presence exists on the northwestern side of the site by Droyer Street. Associated with the ^{234}Th anomalies are generally ^{226}Ra and ^{232}Th daughter anomalies in the same general area. The mean value of ^{234}Th in this area is about 10 pCi/g (see Appendix C, Table II), whereas the ^{226}Ra is less than 2 pCi/g as inferred from ^{214}Pb and the ^{232}Th is also less than 2 pCi/g.

From the surface survey data there was only one small area, located on a concrete pad, which suggested that the guideline may be exceeded. The maximum value for ^{234}Th for this area was 32 pCi/g at GP (65,170). At GP (65,170) a reading of 26 pCi/g (pooled ^{234}Th peaks) was found but the other in situ measurements taken nearby were less than 12 pCi/g ^{234}Th. A small section of the pad at GP (65,175) was removed and soil samples were taken from under the concrete. The results of analysis on these samples indicated activity above background but less than 8 pCi/g of ^{234}Th.

The surface survey together with the trenched soil survey assures that the guideline for ^{238}U is met for the top 20 cm of soil. The surface survey alone shows that the first 10 cm of soil are less than 40 pCi/g ^{238}U. The in situ measurement system for the subsurface (discussed in the following paragraphs) discovered no 20 cm layer containing greater than 40 pCi/g of ^{238}U.

Subsurface -- The subsurface data collected by the in situ measurement system requires more interpretation. Since the spread spoils pile came from a meter deep trench, and guideline dealt with a 20 cm interval, a 5:1 dilution factor could result from the spreading.

In areas where trench spacing was 5 m no group of 16 means (which would be equivalent to 400 m^2) in the suspect areas, when multiplied by the dilution factor of 5, is as large as 40 pCi/g.

Other areas of the Kellex subsurface, measured from trenches spaced 20 m apart whose spoil piles were surveyed at 10 m intervals, would have to show four neighboring measurements whose ^{234}Th were greater than the New Jersey mean to be worthy of further investigation of the 40 pCi/g guideline. No such sets exist.

The soil sample results showed two areas on the site with radionuclide concentration significantly greater than other areas. These two areas are essentially the same ones delineated by the in situ measurement system.

One area is on the concrete pad near GP (65,175). This pad was the location of the laboratory building of the Kellex Research Facility so higher concentrations were not unexpected. The other area is around GP (60,110) and (35,90). Soil samples here were taken near several of the isolated "hot spots" that had received remedial action previous to this survey.

Although small quantities of contaminated material were found by the soil sample analyses and in situ measurement system, there was not sufficient volume to exceed the guideline over a particular 400 m^2 area.

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APPENDIX A

DECONTAMINATION CRITERIA FOR THE FORMER KELLEX SITE (PIERPOINT PROPERTY) REMEDIAL ACTION, JERSEY CITY, NEW JERSEY

U.S. DEPARTMENT OF ENERGY
WASHINGTON, D.C. 20545

Current Federal Policy and Guidance

The current guidance for Federal decisions affecting the exposure of members of the public in the U.S. remains that recommended by the Federal Radiation Council (FRC) and issued by the President in 1960. This guidance defines the Radiation Protection Guide as "the radiation dose which should not be exceeded without careful consideration of reasons for doing so; every effort should be made to encourage the maintenance of radiation dose as far below this guide as practicable."

For members of the public the FRC guidance is: ". . . it is our basic recommendation that the yearly radiation exposure to the whole body of individuals in the general population (exclusive of natural background and the deliberate exposures of patients by practitioners of the healing arts) should not exceed 0.5 rem." In a paragraph particularly suited to our problem, the FRC states "Under certain conditions, such as widespread contamination of the environment, the only data available may be related to average contamination or exposure levels. Under these circumstances, it is necessary to make assumptions concerning the relationship between average and maximum doses. The Federal Radiation Council suggests the use of the arbitrary assumption that the majority of individuals do not vary from the average by a factor greater than three. Thus, we recommend the use of 0.17 rem for yearly whole-body exposure of average population groups." There is urging of the use of reason and judgement and an admonition that the average figure should be applied only when there is a probability of appreciable homogeneity concerning the distribution of dose within the population considered in the average.

These numbers are for whole-body dose and give little guidance for internal organs. However, in applying these guides, the FRC used 1.5 rem/y for the thyroid and 0.5 rem/y for bone marrow. For bone they give an alternate guide of 0.003 Ci for ^{226}Ra in the adult skeleton, that corresponds to about 1 rem/y. In the

derivation of limits for D&D 0.5 rem/y has been used to apply to any organ although one could argue that a limit of 1.5 rems/y was intended for organs such as bone or lung.

The FRC was abolished when the U.S. Environmental Protection Agency (EPA) was created and the responsibilities were assumed by the EPA. The guidance developed by the FRC is still applicable although the EPA has proposed much more restrictive guidance for specific situations based upon what is considered by them as technically and economically practicable for the situation. The proposed drinking water limits and transuranics in soil limits, as well as the basis for Uranium Fuel Cycle Standard, consider the costs of implementation compared to the benefits derived from the use of the standard. The dose equivalent limits proposed or recommended for these specific sources of exposure are included in Table 1.

Recent ICRP Guidance

The International Commission on Radiological Protection (ICRP) recently published revised guidance in ICRP Publication 26, "Recommendations of the International Commission on Radiological Protection." For individual members of the public, they recommend a limit of 500 mrem to the whole body or the equivalent risk if the dose is distributed non-uniformly. They recognized that this limit when applied to an individual normally results in an average annual dose equivalent to the population of less than 100 mrem or an individual risk in the range of 10^{-6} - 10^{-5} per year. The limit of 500 mrem is also considered adequate to assure that no one or group of individuals will be expected to bear an undue portion of the health related cost. The ICRP goes on to further state that any manmade contribution to the radiation exposure of a population must be justified by its benefits.

TABLE 1 - ENVIRONMENTAL STANDARDS

General Environmental Standards

Organization	Annual Limit	Comments
FRC-EPA	500 mrem	whole body, bone marrow
FRC-EPA	170 mrem	whole body, bone marrow (exposure to average population groups)
ICRP	500 mrem	whole body or equivalent risk from organ doses

Specific Environmental Standards

EPA Fuel Cycle Standard (Effective December 1980)	75 mrem	thyroid
	25 mrem	whole body or other organ (Rn and daughters excluded)
EPA Drinking Water Standard	4 mrem/y	manmade beta-gamma emitting radioactivty
	5 pCi/l	^{226}Ra or ^{228}Ra
	15 pCi/l	gross alpha measurements
EPA Proposed Guidance for Transuranics	1 mrad*	lung
	3 mrad**	bone

*This is equivalent to approximately 20 mrem
**This is equivalent to approximately 150 mrem

For exposure to radiation such that the organs receive different doses, the ICRP recommends that the "dose limitation be based on the principle that the risk should be equal whether the whole body is irradiated uniformly or whether there is non-uniform irradiation." This is achieved by converting the partial body dose equivalents to whole body dose equivalents by multiplying the organ dose equivalents by weighting factors (Wt) that express comparative risk factors, provided in Table 2, for each organ, and comparing the sum with the whole-body dose equivalent limit.

TABLE 2 - ORGAN WEIGHTING FACTORS USED BY THE ICRP IN RELATING ORGAN DOSES TO WHOLE BODY DOSE

Tissue	Wt
Gonads	0.25
Breast	0.15
Red Bone Marrow	0.12
Lung	0.12
Bone Surfaces	0.03
Remainder	0.30

Rationale for Cleanup Limits and Sampling Methodology for Soils at the Keilex Site

In proposing limits for soil contamination, it is important to identify the principal pathways of radiation exposure to man and provide soil limits and measurement methodologies which are appropriate for limiting exposure via those particular pathways. The most recent analysis of the hazards associated with soils contaminated with uranium has been done by J.W. Healy, J.C. Rodgers, and C.L. Wienke, "Interim Soil Limits for D&D Projects," Draft LA-UR-79-1865-Rev. (September 1979). In their analysis they estimated, on a conservative basis, the soil contamination levels necessary to deliver a dose equivalent of 500 mrem/y to the organ receiving the highest annual dose of the maximum exposed individual. Their analysis demonstrates that the significant pathway to man is from ingestion. Since surface waters are not consumed, a home gardener living on the site all of his life who grew all of the fruit and vegetables which he ate would be considered the most severely exposed individual. For this extreme situation, the study predicts that a garden with an average concentration of 18 pCi/g of ^{238}U would produce a bone dose equivalent of less than 500 mrem/y. In the analysis, the effects of ^{234}U were included with the ^{238}U since they are normally in secular equilibrium, i.e., the disintegration rates per soil mass are equal for ^{234}U and ^{238}U. The next most restrictive pathway was shown to be inhalation where continuous occupancy of a large site having a soil concentration of 750 pCi/g of ^{238}U would correspond to a maximum lung dose of less than 500 mrem.

The 18 pCi/g limit for ^{238}U is based upon a very conservative estimate of a quantity that leads to a dose of 500 mrem/year to the highest organ at any time during the lifetime of an individual who has the highest intake of uranium from the contaminated area. Because the inhalation is a minor problem compared to ingestion of foods from the area, the lung is only slightly

involved and the bone-surface becomes the critical organ. If we consider only the bone as irradiated, the new ICRP formulation would indicate that this would be equivalent to a whole-body dose of 15 mrem/y. However, because other organs such as kidney and liver are undoubtedly irradiated also, a more realistic value is on the order of 20-50 mrem/y.

Since the pathway analysis demonstrates that home gardening is by far the most significant concern when using land contaminated with uranium, the soil sampling methodology and limits are being selected accordingly. Garden crops normally extract most of their nutrients from the uppermost 20 cm of soil so that sampling must assure that a garden capable of producing a significant fraction of a person's vegetables will not have an average contamination level in the top 20 cm of soil greater than the proposed limit. The size of a garden plot which could supply this quantity of food is assumed, for purposes of the cleanup, to be 400 square meters. This size is based upon an estimate provided by personnel at the U.S. Department of Agriculture. Dr. Ray Webb of that Department stated that a fertile garden of 1/4 acres (1,000 m^2) could supply all the vegetables for a family of four. Allowing an additional 50 m^2 for each of several fruit trees and assuming only one person per household, the minimum size of concern would be approximately 400 m^2.

The Kellex site (Pierpoint Property) is not suitable for home gardening or other agricultural uses at present. The site has been used to deposit waste soils, cinders, and other rubble for many years. These materials would have to be removed or replaced with more fertile top soil before a large fraction of a man's diet could be grown on a 400 m^2 plot. The effect of bringing in top soil would be to reduce the contamination in the root zone to a small fraction of the initial concentration. This dilution factor should be considered when establishing a maximum allowable limit for this site as described below. One might argue that the plot size could be enlarged and thus the most

conservative limit should be retained. We believe that enlarging the garden plot size in this case would also reduce the average uranium concentration, for the contmination has been found in small isolated areas and enlarging the area would have a net result of lowering the average uranium concentratin. After considering the physical properties of the land, and the unlikelihood that a family would desire to eat only fruits and vegetables grown on that plot, we estimate that a residual limit of 40 pCi/g of ^{238}U (rather than 18 pCi/g) averaged over 400 m^2 would correspond to less than 500 mrem/y to the bone of the maximum exposed individual. This site specific adjustment factor of approximately 2 is still considered very conservative.

Throughout the cleanup, the principle of As Low As Reasonably Achievable (ALARA) will be applied. The degree and costs of decontamination depend to a great extent upon the ability to detect the contaminant with field instruments. It is normally impractical to assure that decontamination to levels below the detection limit of the field instruments will be achieved. The practical detection limit for presently available field instruments is about 20 pCi/g for uranium-238. Therefore, soils sampled and found to exceed 20 pCi/g will be removed from the top 20 cm layer during remedial action. Since the contamination on this site is expected to occur in small areas compared to 400 m^2, we anticipate that the average contamination for any 400 m^2 will be a small fraction of the 40 pCi/g limit.

Surface exploration will be made in suspected contaminated areas by trenching or other methods. Considering the past uses of the site, exploring to a depth of about 3' will be adequate unless indications of burial of radioactive material are found, and then it will be necessary to go deeper. Care will be taken to explore enough of the subsurface in areas of suspected contamination such that a high degree of assurance is provided that significant quantities of contaminated soils have been located

and removed. (A "significant quantity" in this context is defined as a quantity of activity capable of exceeding the soil limits (40 pCi/g) if brought to the surface and mixed with the top soil.) Furthermore, subsurface soil below 20 cm depth identified as contaminated above the sensitivity of the field instruments (20 pCi/g) will be removed to the extent it is practical.

Uranium-238 Soil Limits and Cleanup Criteria*

Soil Limit
40 pCi/g

*Average concentration in the top 20 cm of soil averaged over a 400 m^2 area as specified in the implementation section. The limit of 40 pCi/g has been increased from 18 pCi/g because of site specific considerations (see text).

Implementation

1. A gamma-ray survey or combination of gamma-ray and alpha survey will be made to locate contaminated areas exceeding 20 pCi/g uranium-238 to a depth of 20 cm. All contaminated soil within this depth found to exceed 20 pCi/g will be removed from these areas.
2. In areas where subsurface deposits are suspected, a plan for subsurface sampling shall be followed which will identify and remove quantities of contamination capable of exceeding the soil limit (40 pCi/g) for the Kellex site, if under any possible future land use, this contaminated soil were to be brought to the surface.
3. After decontamination of the site, the excavated areas will be backfilled with clean soil or leveled.

4. A final survey will be performed to describe the condition of the site after cleanup. The following procedure will be followed unless an alternative procedure is agreed to by the DOE and the State of New Jersey. All decontaminated areas will be divided into grid systems described by perpendicular lines 4 m apart, thus forming individual grid blocks of 16 m^2 each. Decontaminated areas larger than 400 m^2 will be subdivided into 2 or more approximately equal subareas of less than or equal to 400 m^2 each. Soil samples from each 16 m^2 area will be taken to a depth of 20 cm. A composite sample will be made from sample aliquots from each 16 m^2 grid block and analyzed, representing the average concentration of the 400 m^2, or less, area. If the average concentration exceeds 20 pCi/g uranium-238, the analyses of the soil samples from the 16 m^2 area will be used to guide further remedial action.

Certification

During cleanup operations, the remedial action radiological support contractor will collect and document radiological data from analyses of soil samples and portable radiation detection instruments to determine the adequacy of decontamination. Concurrently and independently, the DOE Office of Environment's survey contractor will collect and analyze spot soil samples and make in situ radiological measurements.

After completion of the remedial actions, the Office of the Environment's survey contractor will conduct an onsite survey to establish the final radiological condition. Using the data documented by the remedial action contractor and the independently collected radiological data, the Office of Environment will determine the status of certification.

APPENDIX B

DERIVATION OF THE SAMPLING PLAN

Basically the criteria document specified that remedial action would be necessary if at least one of two conditions existed. Remedial action would be necessary if the top 20 cm of soil over a 400 m^2 area contained an average concentration of ^{238}U 40 pCi/g or more. Second, if a layer of subsurface contamination existed which when brought to the surface would cause criteria to be met or exceeded, remedial action would be necessary. Since this survey would only be a characterization of the radiological nature of the Kellex site and no remedial action involved, this criteria served as our guideline. Therefore, the sampling plan developed would need to provide a high degree of confidence that significant quantities of contaminated soil have been located. To make the most effective use of available resources the subsurface soil of contaminated areas discovered by earlier surveys would be explored carefully. In conjunction with this and the information gained from the surface survey for this project the initial spacing for the subsurface plan was determined. Spacing would be reduced if evidence of contamination was found in unsuspected areas to better delineate contaminated regions and provide sampling flexibility.

To estimate the probability of detecting a zone of contamination it is necessary to model its characteristics. Based on what was found during the remedial action by Enviroshpere it is assumed that subsurface zones of contamination are circular disks. The highest concentration of ^{238}U found during this remedial action was 2000 pCi/g. If a disk 20 cm in thickness and 3.2 m in diameter with an average concentration of 2000 pCi/g of ^{238}U was spread over a 400 m^2 area, the resulting concentration would exceed our guideline. Assuming the maximum concentration of ^{238}U found at Kellex was 2000 pCi/g, any disk with concentration of

^{238}U less than this would have to be larger thus having a greater probability of being located. Using this assumption the probability of detecting our minimum diameter disk (3.2 m) is a lower bound to the probability of detecting a zone of contamination exceeding our guideline.

It is possible to find a 3.2 m diameter disk (or any size disk) with probability one. To accomplish this, one could drill holes a distance apart equal to the length of a side of the largest inscribable equalateral triangle in a 3.2 m diameter disk. However, the number of holes to be surveyed is inversely proportional to the diameter of the disk, i.e., the smaller the disk the greater number of holes. For the Kellex site more than 22,000 holes would be needed!

With the availability of prior information of where possible regions of contamination existed and with the desirability of using a trenching methodology a more feasible sampling plan was possible. If parallel trenches were dug 3.8 meters apart with a 60 cm wide bucket (or wider) the probability of locating a 3.2 m diameter disk is equal to unity. Since digging trenches closer than 5 m apart (parallel trenching) was not feasible for safety considerations, the probability is .76 that such a disk would be found using a 60 cm bucket. During the project a bucket of 106 cm width was used giving a probability of .85 for locating a 3.2 m diameter disk when trenching on 5 m centers.

APPENDIX C

Table I. Locations on the 20 m grid where radionuclide concentrations differed significantly from the New Jersey mean level as measured by the in situ system.

	GP Location		Concentration (pCi/g)	
Radionuclide	x(m)	y(m)	Mean	Standard Deviation
^{234}Th	40	80	8.8	1.9
(pooled)	60	80	8.2	2.0
	60	180	8.5	1.7
	80	40	6.5	2.1
	100	320	5.7	2.2
	120	100	6.6	2.1
	120	320	8.3	2.3
^{226}Ra	(none)			
^{214}Pb (pooled)	(none)			
^{212}Pb and ^{208}Tl (pooled)	(none)			

TABLE II. Locations on the 5 m grids where in situ measurements indicated concentrations differing significantly from the New Jersey mean level.

	GP Location		Concentration (pCi/g)	
Radionuclide	x(m)	y(m)	Mean	Standard Deviation
^{234}Th	35	90	17.8	2.0
	40	85	17.4	1.9
	40	90	10.8	1.8
	45	60	11.2	1.8
	45	85	12.0	1.7
	45	90	11.3	1.8
	50	55	16.4	1.9
	50	85	13.2	1.8
	50	90	19.2	2.0
	50	95	11.0	1.8
	50	100	11.6	1.9
	55	110	15.2	1.9
	55	115	11.8	1.9
	60	85	9.2	1.8
	60	115	12.9	1.8
	60	125	13.2	1.9
	65	165	9.6	1.4
	65	170	27.6	1.8
	65	185	9.4	1.4
	65	175	26.2	1.7
	70	170	8.2	1.3

TABLE II (Continued)

Radionuclide	GP Location x(m)	GP Location y(m)	Concentration (pCi/g) Mean	Concentration (pCi/g) Standard Deviation
^{226}Ra*	35	90	4.8	.9
	40	85	5.4	.9
	45	60	5.4	.9
	45	90	4.7	.9
	50	55	8.6	1.0
	50	90	6.4	.9
	55	80	4.1	.9
	55	110	5.2	.9
	55	115	4.4	1.0
	57.5	177.5	4.0	.9
	60	115	5.7	.9
	60	125	5.0	.9
	65	170	6.1	.7
	65	175	6.0	.7
^{214}Pb (pooled)	(none)			
^{212}Pb & ^{208}Tl (pooled)	(none)			

*^{226}Ra concentration determined from the 186 keV photopeak.

TABLE III: Locations from the subsurface survey where radionuclide concentrations differed significantly from the New Jersey mean level as measured by the in situ system.

Radionuclide	GP Location x(m)	GP Location y(m)	Concentration (pCi/g) Mean	Concentration (pCi/g) Standard Deviation
^{234}Th (pooled)	35	90	21.8	2.1
	40	90	7.5	1.8
	45	55	8.2	1.7
	45	85	5.8	1.5
	45	90	6.8	1.5
	45	100	7.4	1.5
	50	85	7.2	1.6
	50	90	7.4	1.6
	50	95	6.5	1.5
	55	30	5.2	1.9
	55	110	6.4	1.6
	60	85	5.4	1.6
	80	195	7.9	1.9
	80	205	9.2	1.9
	90	162.5	5.7	1.5
	90	167.5	6.1	1.6
	135	105	5.4	1.6
	145	110	5.7	1.8
	160	165	5.6	2.0
	160	315	5.2	1.9
	164	115	5.1	1.5

TABLE III (Continued)

Radionuclide	GP Location x(m)	GP Location y(m)	Concentration (pCi/g) Mean	Concentration (pCi/g) Standard Deviation
^{226}Ra*	35	90	5.3	.9
	40	90	4.2	.9
	45	55	5.4	.8
	80	205	4.2	.9
^{214}Pb (pooled)	(none)			
^{212}Pb & ^{208}Tl (pooled)	(none)			

*^{226}Ra concentrations determined from 186 keV photopeak.

TABLE IV. ^{234}Th results from soil samples given wet chemistry analysis

GP Location			^{234}Th	
x(m)	y(m)	Depth (cm)	pCi/g	Comment
35	85	5	<3.7	adjacent to hot spot GP (35,90)
35	85	15	<2.8	" " " " " "
35	85	25	<3.0	" " " " " "
35	85	75	<2.6	" " " " " "
35	90	surface	310 ± 10.0	Hot spot
40	90	15	<10.0	adjacent to hot spot GP (35,90)
45	30	25	<6.6	" " " " " "
45	95	25	<10.0	" " " " " "
45	105	45	<10.0	near hot spot at GP (35,90)
50	100	45	<5.9	" " " " " "
55	90	15	<10.0	" " " " " "
55	105	5	<10.0	" " " " " "
60	120	25	<10.0	" " " " " "
65	95	5	<10.0	NJ sample area*
65	95	15	<8.7	" " "
65	95	25	<6.1	" " "
65	95	45	<6.6	" " "
65	95	75	<7.8	" " "
65	110	5	<12.0	near hot spot at GP (35,90)
65	175	surface	160 ± 20.0	surface of concrete pad
65	175	15	7.3 ± 2.5	under concrete pad
65	301.5	45	<15.0	high Ge(Li) scan
80	45	5	<8.6	NJ sample area*
80	45	15	<9.1	" " "
80	45	25	<7.8	" " "
80	45	45	<9.1	" " "
80	45	75	<11.0	" " "

*Samples taken at these locations were in addition to samples taken by the Jersey Bureau of Radiation Protection.

TABLE IV (continued)

GP Location x(m)	GP Location y(m)	Depth (cm)	^{234}Th pCi/g	Comment
80	94	75	<7.0	NJ sample area
80	235	5	<3.7	High Ge(Li) scan
100	255	45	<4.1	Bias location
120	95	75	<10.0	NJ sample at GP (120,99.5)
120	105	75	<7.2	" " " " "
135	105	45	<10.0	Adj. higher reading location
135	105	75	<10.0	" " " "
135	110	5	6.5 ± 3.6	Bias location
135	110	15	<3.7	" "
135	110	25	<5.7	" "
135	110	45	<5.0	" "
135	110	75	5.8 ± 3.9	" "
140	15	25	<9.7	Higher instrument reading
140	108	45	<10.0	" " "
140	108	75	<10.0	" " "
140	185	5	<10.0	" " "
140	185	15	<10.0	" " "
140	185	25	<10.0	" " "
140	185	45	<10.0	" " "
140	185	75	<10.0	" " "
145	100	75	<10.0	" " "
150	109	5	<4.6	Bias location
150	109	15	<4.1	" "
150	109	25	<5.2	" "
150	109	45	<4.8	" "
150	109	75	<5.5	" "
160	159	5	<5.1	" "
160	159	15	<4.6	" "
160	159	25	<4.4	" "
160	159	45	<5.0	" "
160	159	75	<5.9	" "

TABLE IV (continued)

GP Location			^{234}Th	
x(m)	y(m)	Depth (m)	pCi/g	Comment
160	305	75	<10.0	Bias Location
160	327	45	<4.5	" "
172.5	112.5	75	<10.0	" "
185	84	45	<9.4	" "
220	45	75	<5.2	" "
300	25	5	<10.0	" "
300	25	25	<10.0	" "
300	25	75	<10.0	" "

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